INTERMOUNTAIN POWER SERVICE CORPORATION

☑ REQUISITION FOR CAPITAL EQUIPMENT

☐ PURCHASE AUTHORIZATION FOR EXPENSE ITEMS

Purpose of Materials, Supplies or Services:

Replacement LP turbine last stage buckets and installation

Date:	
Req./PA No:	248375
P.O. No:	
Vendor:	
Terms:	
FOB:	
Ship Via:	
Conf. To:	

Suggested Vendor: Competitive Bid

Account No. 00-1TGX-402
Work Order No. 09-68785-0
Project No. IGS-09-03

Qty	Unit	Description: Noun / Adjective / Catalog # / Seller or Manufacturer	Unit Cost	Extension
1	1	Unit 2 replacement LP turbine last stage buckets and installation for Spring 2010 outage.		$6,035,000.00
	1	Unit 1 replacement LP turbine last stage buckets and installation for Spring 2011 outage.		$6,035,000.00
		TOTAL ESTIMATED COST		$12,070,000.00

Remarks:

Delivery requested by [Date] 04-27-10 Originator Spence

Dept. Mgr/Supt. Date Station Manager Date Operating Agent Date

IP7017718

LIST OF SUGGESTED BIDDERS

1. GE Energy
   Attention: Rob Ruotsi
   2180 South 1300 East, Suite 340
   Salt Lake City, UT 84106
   Telephone: 801-468-5725
   Fax: 801-468-5767
   Cell: 801-870-4365
   email: robert.ruotsi@ge.com

2. Mechanical Dynamics and Analysis, LTD
   Attention: Janet Reville, Contracts & Proposals Manager
   29 British American Blvd.
   Latham, New York 12110
   Telephone: 1-800-999-4632
   email: jreville@mdaturbines.com

3. TuboCare, Inc.
   Attention: Dan Johnson, Regional Sales Manager
   4025 East Cotton Center Blvd.
   Phoenix, AZ 85040
   Telephone: 602-567-2223
   Cell: 602-317-5400
   email: djjohnson@turbocare.com

4. Alstom Power
   Attention: Christopher Johnston, Turbine Products Manager
   2800 Waterford Lake Drive
   Midlothian, VA 23112

5. Toshiba International Corporation
   Attention: Kurt Edelbach, STG Product Manager - Service Department
   Power Systems Division
   6610 West Greenfield Ave.
   West Allis, WI 53214
   Telepnone: 610-675-7582
   email: kurte@toshibatic-pa.com

PART C - DIVISION C3

BIDDING DOCUMENTS - ADDITIONAL BID INFORMATION

Detailed Information: The bidder shall furnish the following detailed information for **Unit 1 and Unit 2 LP Turbines Last Stage Bucket Replacement**:

1. Complete the proposed performance table contained in Table F3-2

2. Detailed schedule for completion of the Work.

3. List of recommended spare parts with prices.

4. List of previous installations with contact names and telephone numbers. Please highlight any and all experience on similar size, model, and generator manufacturer.

5. Anticipated payment and milestone schedule.

6. Resumes for key personnel involved with project.

PART E - DIVISION E1

GENERAL CONDITIONS

19. Performance Incentives and Liquidated Damages: The timely completion of the LP Turbines Last Stage Bucket Replacement is of critical importance to the economic operation of the IGS and IPSC will suffer significant damages as a result of such delay.

The Contractor shall guarantee that the outage schedule for the base scope of work shall be XX days or less as measured from the time the first LP turbine rotor is removed until such time that the Contractor releases the last (third) rotor to IPSC for reinstallation.

The Contractor shall also have a grace period of two (2) days after the aforementioned completion date to complete the work. During this grace period the Contractor shall not be liable to IPSC for liquidated damages.

The parties agree that the Contractor shall be liable to IPSC as fixed, agreed and liquidated damages for each 24 hour period, or fraction thereof, of delay. If the Contractor fails to complete the work within the time specified herein as a result of causes which are within the reasonable control of the Contractor, the Contractor shall pay liquidated damages to IPSC at the rate of One-Thousand Dollars per hour ($1000/hr) for each hour beyond the two (2) day grace period.

Base date for calculation of these dates will be documented upon contract execution and validated based on actual start dates.

Liquidated damages are contingent on "Balance of the Plant" (BOP) availability and will not be enforced unless the BOP is ready to commence operation.
The liquidated damages payable for each generating unit regarding schedule shall not exceed 5% of the per unit base contract price (50% of the total base contract). The payment or crediting of liquidated damages shall be in lieu of actual damages for schedule delays and will be IPSC's sole and exclusive remedy for schedule delay as identified herein.

PART E - DIVISION E2

ADDITIONAL GENERAL CONDITIONS

1. Warranty: **Contractor warrants for a period of two (2) years after the installation of each set of LP turbine last stage buckets,** that all materials, services, equipment, and other Work furnished are free from defects in material, workmanship, and title, and otherwise conform to the terms of the Contract, including, but not limited to, Part E, Division E1, General Conditions, Article 2, Materials and Work. Any cause of action arising out of this warranty must be commenced within thirty-six (36) months from the date Contractor completes its Work under this Contract Agreement (including installation, testing, start-up, and placement of the Work into service). IPSC shall make the equipment and other Work available to Contractor at mutually agreeable times for inspection and/or remedial warranty work during the 36-month limitations period before commencing any action for breach of warranty.

PART F - DIVISION F1

DETAILED SPECIFICATIONS - SPECIAL CONDITIONS

1. General: Under the terms of the Contract, Contractor shall furnish, deliver, and install **Unit 1 and Unit 2 LP Turbine Last Stage Buckets** ordered by IPSC beginning with date stated in the first introductory paragraph of the Contract Agreement.

PART F - DETAILED SPECIFICATIONS

DIVISION F2 - SCOPE OF WORK AND SUPPLY

1. General: This Division describes the general Scope of Work and delineates responsibilities for material supply and construction services.

2. Schedule: The replacement of the Unit 2 LP turbines last stage buckets will occur during the Unit 2 outage currently scheduled to begin **March 27, 2010**. The replacement of the Unit 1 LP turbines last stage buckets will occur during the outage scheduled to begin April 1, 2011. **The length of the outage will depend on the response to this proposal and other work that might occur during the same outage.** IPSC reserves the right to change the outage schedule as needed to accommodate other work and for load dispatch. IPSC will inform Contractor of any changes to the outage schedule as soon as possible and will work with Contractor to ensure that the necessary materials and labor are available for the new outage time.

3. Contractor Scope of Work: Contractor shall supply all necessary materials, supervision, labor, equipment, vehicles, supplies, services, tools, or other similar items, as required, for replacement of the LP turbines last stage buckets except as specified herein.

   The Work shall include, but not be limited to, the following tasks on both Units:

   a. Removal of all LP turbine last stage buckets.

   b. Provide new replacement stellite shielded LP turbine last stage buckets.

   c. Provide two new spare replacement stellite shielded last stage buckets (one for each end/direction).

   d. Rotor boresonic testing on each LP turbine rotor including removal and installation of rotor bore plugs.

   e. Rotor dovetail phased array ultrasonic testing.

   f. Installation of new LP turbine last stage buckets.

   g. Low speed balancing of LP turbine rotors.

   h. All drawings, documentation including pin diagrams, and training necessary for the long-term operation and maintenance of the replaced LP turbine buckets.

   i. All other work necessary to complete the project that is not clearly specified as being provided by IPSC or others.

4. Work Provided by IPSC: The following work shall be the responsibility of IPSC:

   a. Disassembly of the LP turbines and removal of the LP turbine rotors.

   b. Reinstallation of the LP turbine rotors and assembly of the LP turbines.

c. Overhead crane support for moving rotors and contractor equipment.

d. Receive, unload, and store new buckets and installation materials.

e. Transport materials from plant storage areas to the assembly area.

5. Materials and Equipment Supplied by Contractor: Unless specified otherwise, Contractor shall supply all materials and services necessary for completion of the Work. This includes, but is not limited to, the following:

   a. New replacement LP turbine last stage buckets, tenons, and covers.

   b. New last stage bucket dovetail pins.

   c. All tooling required for removal and installation of the last stage buckets.

   d. All other materials necessary for completion of the Work not clearly specified as being supplied by IPSC or others.

6. Materials and Equipment Supplied by IPSC: The following materials and equipment shall be supplied by IPSC:

   a. Rigging for moving LP turbine rotors.

   b. IPSC's overhead cranes will be available for Contractor to use as needed to perform the Work. Contractor shall communicate with, and coordinate their work with IPSC to minimize interference with other turbine and generator work. IPSC will provide an Operator for the crane.

7. Submittals: The following information shall be submitted for approval to IPSC as indicated:

Item	No. of Copies	Description	Schedule
1	2	Contractor's safety and accident prevention plan	Thirty (30) days prior to mobilization
2	2	Contractor's drug policy and drug free testing statements for all employees	Thirty (30) days prior to mobilization
3	2	Contractor's insurance information and indemnification statement	Fourteen (14) days after award of contract
4	2	Detailed fabrication schedule	Fourteen (14) days after **start of engineering**

5	2	Resumes of key personnel that will be directing and completing the Work	**Eight (8) weeks prior to installation**
6	2	Detailed construction and installation schedule with a lay down plan	One-Hundred Eighty (180) days prior to installation
7	2	Estimated payment percentage schedule by month	With proposal
8	10	Manufacturer's data sheets, drawings and performance data for all equipment and materials supplied by Contractor. <u>Drawings shall be AutoCad format.</u>	Thirty (30) days prior to shipment of the materials
9	2	Quality control plan for material fabrication	Thirty (30) days prior to equipment fabrication
10	2	Quality control plan for field installation	Thirty (30) days prior to mobilization
11	2	Post-outage final report (hard copy and electronic)	Sixty (60) days after completion of the Work

8. <u>Construction Utilities</u>: Construction utilities required for the performance of the Work shall be provided by Contractor or IPSC as herein specified:

    a. <u>Office Space and Communication Services</u>: IPSC will provide office space for one (1) employee with telephone and internet connection in the area of the Work. A fax machine and printer will also be available in the office area. It is the responsibility of Contractor to provide their own computers for connection to the internet. Additional connections will be provided as availability allows.

    b. <u>Compressed Air</u>: IPSC will provide compressed air at existing service locations. Hoses for distribution and use are the responsibility of Contractor.

    c. <u>Construction Power</u>: Construction power will be provided by IPSC as needed to perform the Work. The power supplied will be 480 volt. It is the responsibility of Contractor to provide the necessary transformers, distribution panels, and wiring for the end use.

    d. <u>Water</u>: Non-potable water for construction use will be furnished by IPSC at no charge. The connection will be at hose bibs near the construction area. Contractor shall provide all piping, valves, and hoses as required to distribute the water for their use.

       Potable water will only be available at the IPSC Administration building or Site Services Building. Contractor shall provide sanitary drinking water facilities for their employees including coolers, ice, disposable cups, and a trash barrel for each water container or cooler. Each cooler shall be emptied, cleaned, and refilled at the start of each day.

e. Sanitary Facilities: IPSC will provide sanitary facilities for Contractor in the area of the turbine and maintain them during the construction period.

f. Trash Collection: IPSC will provide a truck-mounted trash receptacle for use by Contractor and will empty the trash container as needed. Contractor shall notify the Contract Administrator when the container needs to be emptied. IPSC may take up to three (3) days after notification to empty the container. Contractor shall supply and maintain all other trash containers necessary to maintain a clean and safe work area. Contractor shall not use these trash receptacles for any hazardous waste.

g. Snow Removal: IPSC will provide snow removal service from all onsite roads, parking areas, and around all permanent and temporary construction facilities.

h. Lunch and Break Facilities: IPSC will provide a suitable area near the work area for Contractor's employees to use as a break and lunch facility. A separate Contractor provides food services to IPSC and Contractor's employees between the hours of 11:30 a.m. and 12:30 p.m. on weekdays. Contractor may use those services as they are available and at their own expense.

i. Hazardous Waste Disposal: Contractor shall place all hazardous waste generated by Contractor during the performance of their work in designated containers provided by IPSC. IPSC will be responsible for final disposal.

j. Scaffolding: IPSC will provide all scaffolding needed to perform the Work. Contractor shall notify IPSC as early as possible of their anticipated scaffolding needs.

k. Temporary Lighting: Contractor shall provide all temporary lighting necessary to perform their work.

l. Site Security and Access: The IGS has an existing fence and security system to restrict access to the site. However, the Contractor's work area will not be separated from the rest of the turbine deck and will therefore be accessible by all those approved for site access. It is Contractor's responsibility to protect themselves and their equipment and tools from theft and vandalism as they deem necessary. IPSC will not be responsible for any theft or damage incurred by Contractor.

Only vehicles owned and insured by Contractor or an approved subcontractor will be allowed inside the plant fence perimeter. All other Contractor employees shall park their vehicles outside the fence perimeter at Guard Post #1 located southwest of Unit 2. Contractor shall be responsible for transport of the employees to and from Guard Post #1 and the jobsite. Contractor shall not use the back of trucks for employee transport.

All Contractor employees will be given security badges by IPSC and those badges shall be displayed each day to allow admittance to the plant site. All security badges shall be returned to the security contractor when the employee terminates their work at this site. All Contractor vehicles will also receive parking stickers from the security contractor allowing entrance to the plant site. Temporary badges and parking stickers are available for intermittent Contractor employees and vehicles.

9. Disposal of used replaced Last Stage Buckets and Other Materials: All removed buckets and other metals from the turbine rotors shall remain the property of IPSC. Contractor shall dispose of the removed materials in separate containers for scrap metal that will be provided by IPSC.

PART F - DETAILED SPECIFICATIONS

DIVISION F3 - LAST STAGE BUCKETS DETAILED DESIGN REQUIREMENTS

1. General: This Division contains the requirements for design, manufacture, materials, and factory testing of the Replacement Last Stage Buckets for Unit 1 and Unit 2 low pressure turbines. These buckets are being replaced because of excessive bucket tip leading edge erosion and to reduce the risk of bucket tip failure. After installation, they will be inspected at ten year outage intervals. The replacement buckets should conform to original steam path design, reduce erosion, and prolong the service life of the buckets.

2. Codes and Standards: The applicable sections of the following codes and standards shall be followed during the execution of this work:

3. Current Turbine Design and Operating Parameters: Current turbine design and operating parameters are shown in Table F3-1. IPSC will provide operating heat balance diagrams and current last stage bucket exhaust loss curves. Note that station electrical output is transmitted via DC transmission system. This transmission system has inherent subsynchronous resonance frequencies that effect LP turbines last stage bucket integrity.

4. Effect of Replacement Last Stage Buckets on Turbine Operation: The Contractor shall provide the following information showing the effect of their replacement buckets on operation of the Intermountain Generating Station turbine generators.

    a. Exhaust loss curves.

    b. Expected change in last stage efficiency.

    c. Condenser back pressure limit curve including alarm and trip points.

    d. A study of the Intermountain Generating Station Unit 1 & 2 turbine generators torsional and lateral natural frequencies showing that the original design criteria shall be met with the replacement last stage buckets installed.

    e. Moment weights for each bucket (measured to the nearest 0.01 lb-in) and installation bucket distribution plans to minimize the total "out of balance" forces on each LP turbine rotor shall be provided when the buckets are delivered.

5. Structural Reliability of Replacement Last Stage Buckets: The Contractor shall provide the following information to demonstrate the structural reliability of their replacement last stage bucket design:

    a. A reference list showing installations and history of the Contractor's last stage buckets installed in similar applications (GE S2 ~~or G2~~, 30" last stage buckets, 3600 rpm steam turbines).

    b. Finite element analyses of the last stage bucket design at zero and operating speed, showing calculated steady operating stress, low cycle fatigue crack initiation and life cycle limits for each bucket structural feature.

c. Dynamic analysis of bucket-disk natural frequencies at operating speed showing the first ten nodal diameter frequencies at each of the fundamental bucket modes. Show that each of the at-speed natural frequencies are tuned to provide a margin of at least 15 Hz from the nearest per-revolution force.

d. A description of bucket surface finishing procedures and coating applications. Final airfoil finish shall be 70-80 microinches or better.

e. Bucket design features that prevent stress corrosion cracking.

6. Materials: All parts and materials furnished for work in accordance with these Specifications shall be new, unused, and undamaged. All parts and materials shall meet or exceed specifications for original parts and materials used in the turbine. All parts and materials shall be compatible with original parts and materials used in the turbine. The Contractor shall provide detailed material specifications and physical/mechanical properties for their replacement last stage bucket components including:

a. Bucket base material

b. Erosion shield material and attachment process. Contractor shall quote replacement LP turbine last stage buckets with stellite shields attached using EBW (electron beam weld) methods.

c. Bucket dovetail pins and pin map

d. Bucket covers and tennons:

7. Identification: The following shall apply to the last stage bucket manufacture:

a. Contractor shall identify each bucket so that all material lots, supplier, and quality control tests can be traceable to individual buckets.

b. Identification codes shall be stamped on the discharge side of the root of each bucket so that the codes shall be visible with the buckets installed.

8. Quality Control and Testing: A stringent quality control testing program shall be utilized in the manufacture of the replacement buckets. A description of this quality control program listing each manufacturing step and the required tests shall be provided by the Contractor. Fabrication shall not proceed until the IPSC Project Engineer approves the quality control program. This description shall include, as a minimum, the following components and a report shall be provided showing the quality control provided on each of the components:

a. Dimensional checks.

b. NDE and material checks including tests to determine the quality of the erosion shield attachment.

c. Bucket natural frequency tests.

d. Bucket moment weights and arrangement diagrams.

e. Results of the above measurements and tests shall be documented for each bucket and provided to IPSC for review following fabrication and before delivery.

f. Contractor shall ensure that appropriate witness points are included in the manufacturing schedule and they shall advise IPSC at least thirty (30) days prior to each witness point. IPSC will have the ability to enter Contractor's manufacturing facilities at any time to witness a test or fabrication.

9. Proposed Replacement Bucket Design Data Sheet: Contractors shall submit their proposed replacement bucket design and operating information for bid evaluation in the format outlined in Table 3-2.

10. Proposal Cost Table: The Contractor shall provide a breakdown of the proposed project costs in the format outlined in Table 3-3

TABLE F3-1

CURRENT TURBINE DESIGN AND OPERATING INFORMATION

Manufacturer:	General Electric
Serial Numbers:	Unit 1: 270T150, Unit 2: 270T151
Operating Rating:	950 MW
Turbine Type:	S2 (3 double-flow low pressure turbines)
Speed:	3,600 rpm
Throttle Pressure:	2400 psig
Throttle / Reheat Temperatures:	1000F / 1000F
Exhaust Pressure (LPA/LPB/LPC):	2.99"/2.24"/1.66" Hg Absolute
LP Turbine Last Stage Buckets:	S2 **GE Mk IV 30" LSB** self-shielded, Jethete (M152) pinned root (finger type)
# of Last Stage Buckets:	88/row, 176/turbine, 528/unit
Commission Date:	Unit 1: 1986, Unit 2: 1987

need - Heat Balance Diagram
latest Design - 950 MWg w/ Alston HP, design BP

IP7017731

TABLE F3-2

PROPOSED LAST STAGE BUCKET DESIGN & OPERATING DATA

Manufacturer	
Bucket model name	
Effective length	
Weight per bucket (lb)	
Erosion shield material	
Erosion shield attachment	
Bucket base material	
Cover type	
Mid-span support type	
Back-pressure alarm (Hg")	
Back-pressure limit (Hg")	
Efficiency improvement features	
Total installed rows of proposed bucket design	
Oldest installation of proposed bucket design	
Low cycle fatigue life limits	
Resonance detuning acceptance criteria	
High cycle fatigue acceptance criteria	
Stress corrosion cracking - HCF acceptance criteria	
Torsional/lateral frequency analysis criteria/results	
Low speed balance plan	
Low speed balance acceptance criteria	

TABLE F3-3

PROPOSAL COST BREAKDOWN

	Unit 2 (Spring 2010)	Unit 1 (Spring 2011)
Replacement buckets (528/unit)		
Installation		
Spare LSB's (2 total)		
Rotor boresonic inspection		
Rotor dovetail phased array testing		
Total Costs for each Unit		

PART F - DETAILED SPECIFICATIONS

DIVISION F4 - LAST STAGE BUCKETS DETAILED INSTALLATION REQUIREMENTS

1. General: This Division contains the requirements for installation of the LP Turbines Last Stage Buckets on both Units

2. Codes and Standards: Equipment covered in this specification shall comply with all currently approved applicable industry codes and standards, and all federal, state, and local safety and health standards. The codes and standards shall include but not be limited to:

   a. ANSI - American National Standards Institute
   b. ASME - American Society of Mechanical Engineers
   c. ASNT - American Society for Nondestructive Testing
   d. ASTM - American Society of Testing Materials
   e. AWS - American Welding Society
   f. OSHA - Occupational Safety and Health Administration

   Any conflict between the specification(s) and a referenced document shall be referred to the IPSC Project Engineer for clarification.

   Any non-US codes or standards that apply to components supplied under this specification shall be identified in the proposal.

3. Qualified Personnel: Contractor shall provide technically qualified and competent personnel to perform the engineering, design, analysis, calculations, testing and other tasks necessary to complete the Work. The buckets shall be installed by technicians skilled and experienced in bucket installation on large steam turbines.

4. Field Engineer/Technical Director: Contractor shall provide a Field Engineer/Technical Director at the job site during all bucket replacement work. Each shift working on the bucket replacements shall have a competent and experienced Field Engineer/Technical Director to direct the work and provide quality control.

5. Equipment: All Contractor test equipment, tools, and other equipment shall be in good working order. Contractor shall provide IPSC with a list of equipment and tools brought to the IPP job site. Equipment which is normally subject to periodic calibration shall be calibrated within the equipment manufacturer's recommended calibration interval. Calibration certificates clearly identifying the ~~most recent~~ calibration date shall be reviewed with the **IPSC Project Engineer**.

6. Quality Control: It is the responsibility of Contractor to develop and implement their own quality control plan as necessary to complete a quality job. The plan shall contain progressive testing and measurements during the installation of the last stage buckets.

7. Schedule: Installation time will be a factor in awarding the contract. The Contractor shall demonstrate capability to install six rows of last stage turbine buckets concurrently on three LP turbine rotors. The Contractor shall also conduct non destructive testing on the LP turbine rotors including rotor bore ultrasonic inspections and rotor dovetail phased

array ultrasonic testing. This will allow the Contractor to coordinate these additional activities to expedite the last stage bucket installation. IPSC will deliver the LP turbine rotors to the Contractor as soon as they are removed from the turbine shell before any testing or cleaning is conducted. Contractor work on each LP turbine rotor shall be complete when all the last stage buckets are installed, the rotor is low speed balanced to specifications, and, all testing and cleaning are completed.

8. Unit 1 Installation Schedule: Contractor shall install six rows of last stage turbine buckets on three LP turbine rotors during the Unit 1 LP turbines overhaul scheduled to begin on **March 27, 2010**. The Contractor shall provide an estimate of the total time in days required to complete the bucket installation on all three Unit 1 LP turbine rotors. This time estimate shall start when the Contactor receives the first LP turbine rotor on the seventh day of the outage (April 2, 2010) and end when the Contractor delivers the last (third) completed LP rotor to IPSC. The second and third LP turbine rotors will be delivered to the Contractor at approximately one day intervals following the delivery of the first rotor (seventh and eighth day of the outage).

9. Unit 2 Installation Schedule: Contractor shall install six rows of last stage turbine buckets on three LP turbine rotors during the Unit 2 LP turbines overhaul scheduled to begin on **March 26, 2011**. The Contractor shall provide an estimate of the total time in days required to complete the bucket installation on all three Unit 2 LP turbine rotors. This time estimate shall start when the Contractor receives the first LP turbine rotor on the seventh day of the outage (April 1, 2011) and end when the Contractor delivers the last (third) completed LP rotor to IPSC. The second and third LP turbine rotors will be delivered to the Contractor at approximately one day intervals following the delivery of the first rotor (seventh and eighth day of the outage).

IGS07-03 Gen-tech specs

Spec. __

PART F - DETAILED SPECIFICATIONS

DIVISION F2 - SCOPE OF WORK AND SUPPLY

1. General: This section of the contract describes the general scope of work and delineates responsibilities for material supply and construction services.

2. Schedule: The rewind of the Unit 2 Generator will occur during the Unit 2 outage currently scheduled to begin March 27, 2010. The rewind of the Unit 1 Generator will occur during the outage scheduled to begin April 1, 2011. The length of the outage will depend on the response to this proposal and other work that might occur during the same outage. IPSC reserves the right to change the outage schedule as needed to accommodate other work and for load dispatch. IPSC will inform the Contractor of any changes to the outage schedule as soon as possible and will work with the Contractor to insure that the necessary materials and labor are available for the new outage time.

3. Contractor Scope of Work: The Contractor shall supply all necessary materials, supervision, labor, equipment, vehicles, supplies, services, tools, or other similar items, as required, for rewind of the generator stator except as specified herein.

   The work shall include, but not be limited to, the following tasks on both units:

   a. Rewind of the water-cooled generator stator including new connection rings.

   b. Test the core prior to removal of the windings to quantify existing core condition.

   c. Repair any core damage or lamination looseness found during the initial core loop test. This repair work shall be done on a Time and Material basis.

   d. Removal of the existing windings and cleaning of the core and slots.

   e. Repair all damage to the core caused by the rewind. This core repair shall be at no additional cost to IPSC.

   f. Removal and reinstallation of cooling water and electrical connections.

   g. Removal of the existing and reinstallation of new winding RTDs.

   h. Removal of the existing and installation of a new generator flux probe.

   i. Testing of the core and windings after installation.

   j. All fitness-for-service testing of the generator after final assembly.

   k. All drawings, maintenance manuals, documentation, training and as-built drawings necessary for the long-term operation and maintenance of the rewound generator.

l. All other work necessary to complete the project that is not clearly specified as being provided by IPSC or Others.

4. <u>Work Provided by IPSC</u>: The following work shall be the responsibility of IPSC:

   a. Removal of the generator end shields, bearings, collector rings, and generator field.

   b. Reinstallation of the generator end shields, bearings, collector rings, and generator field after the rewind.

   c. Isolation from CO_2 and Hydrogen supply and from electrical power sources.

   d. Miscellaneous Electrical and I&C Technician support as necessary to remove, store, and reinstall the supervisory instrumentation, grounding, thermocouples, and other devices.

5. <u>Materials and Equipment Supplied by the Contractor</u>: Unless specified otherwise, the Contractor shall supply all materials and services necessary for completion of the work. This includes, but is not limited to, the following:

   a. Stator bars, insulation, wedges, and all other materials necessary for the rewind.

   b. New connection rings, end windings, water hoses, connectors, and fittings.

   c. New thermocouples and RTDs.

   d. New generator flux probe.

   e. All miscellaneous fasteners, sealants, weld materials, and consumables.

   f. Temporary construction facilities required by the Contractor.

   g. Generator pressure and vacuum test skid.

   h. EL-CID Test Equipment.

   i. All other materials necessary for completion of the work not clearly specified as being supplied by IPSC or Others.

6. <u>Materials and Equipment Supplied by IPSC</u>: The following materials and equipment shall be supplied by IPSC:

   a. Cable and cable supports for flux-loop testing of the core. Installation of the cable and supports for the test shall be by the Contractor.

b. DC Insulation Resistance and Doble test equipment.

c. IPSC's overhead cranes will be available for the Contractor to use as needed to perform the work. The Contractor shall communicate with, and coordinate their work with IPSC to minimize interference with other turbine work. IPSC will provide an Operator for the crane.

d. The specialty tools supplied with the original purchase of the generator.

7. Submittals: The following information shall be submitted for approval to IPSC as indicated:

Item	No. of Copies	Description	Schedule
1	2	Contractors safety and accident prevention plan	30 days prior to mobilization
2	2	Contractors drug policy and drug free testing statements for all employees	30 days prior to mobilization
3	2	Contractors insurance information and indemnification statement	14 days after award of contract
4	2	Detailed fabrication schedule	14 days after award of contract
5	2	Resumes of key personnel that will be directing and completing the work	14 days after award of contract
6	2	Detailed construction and installation schedule with a laydown plan	180 days prior to installation
7	2	Estimated payment percentage schedule by month	14 days after award of contract
8	10	Manufacturer's data sheets, drawings and performance data for all equipment and materials supplied by the Contractor. Drawings shall be AutoCad format.	30 days after award of contract and prior to equipment fabrication
9	2	Quality control plan for material fabrication	30 days after award of contract and prior to equipment fabrication
10	2	Calculations showing generator efficiency and capacity	30 days after award of contract

11	2	Quality control plan for field installation	30 days prior to commencement of work at the site
12	2	Post-outage final report (hard copy and electronic)	60 days after completion of the work

8. Construction Utilities: Construction utilities required for prosecution of the work shall be provided by the Contractor or IPSC as herein specified:

   a. Office Space and Communication Services: IPSC will provide office space for three (3) employees with telephone and internet connections in the area of the work. A fax machine and printer will also be available in the office area. It is the responsibility of the Contractor to provide their own computers for connection to the internet. Additional connections will be provided as availability allows.

   b. Compressed Air: IPSC will provide compressed air at existing service locations. Hoses for distribution and use are the responsibility of the Contractor.

   c. Construction Power: Construction power will be provided by IPSC as needed to perform the work. The power supplied will be 480 volt. It is the responsibility of the Contractor to provide the necessary transformers, distribution panels, and wiring for the end use. A 6900-volt connection will be provided for the core loop test.

   d. Water: Non-potable water for construction use will be furnished by IPSC at no charge. The connection will be at hose bibs near the construction area. The Contractor shall provide all piping, valves, and hoses as required to distribute the water for their use.

      Potable water will only be available at the IPSC Administration building or Site Services Building. The Contractor shall provide sanitary drinking water facilities for their employees including coolers, ice, disposable cups, and a trash barrel for each water container or cooler. Each cooler shall be emptied, cleaned, and refilled at the start of each day.

   e. Sanitary Facilities: IPSC will provide sanitary facilities for the Contractor in the area of the generator and maintain them during the construction period.

   f. Trash Collection: IPSC will provide a truck-mounted trash receptacle for use by the Contractor and will empty the trash container as needed. The Contractor shall notify the Project Manager when the container needs to be emptied. IPSC may take up to three (3) days after notification to empty the container. The Contractor shall supply and maintain all other trash containers necessary to maintain a clean and safe work area. The Contractor shall not use these trash receptacles for any hazardous waste.

g. Snow Removal: IPSC will provide snow removal service from all onsite roads, parking areas, and around all permanent and temporary construction facilities. The Contractor shall be responsible for snow removal, as needed, around the construction areas not accessible by truck mounted graders.

h. Lunch and Break Facilities: IPSC will provide a suitable area near the work for the Contractor's employees to use as a break and lunch facility. A separate Contractor provides food services to IPSC and contract employees between the hours of 11:30 a.m. and 12:30 p.m. on weekdays. The Contractor may use those services as they are available and at their own expense.

i. Hazardous Waste Disposal: The Contractor shall properly collect, store, and dispose of all hazardous waste generated by the Contractor during the performance of their work.

j. Scaffolding: IPSC will provide all scaffolding needed to perform this work. The Contractor shall notify IPSC as early as possible of their anticipated scaffolding needs.

k. Asbestos Abatement: It is IPSC's belief that no asbestos was used in the original manufacturing and construction of the generator, therefore; no asbestos abatement is anticipated. If the Contractor believes that asbestos is present, it is the Contractor's responsibility to do the testing to verify the presence of asbestos. If asbestos is found and verified, IPSC will be responsible for all costs associated with removal.

l. Temporary Lighting: The Contractor shall provide all temporary lighting necessary to perform their work.

m. Site Security and Access: The Intermountain Generating Station has an existing fence and security system to restrict access to the site. However, the construction site will not be fenced separate from the rest of the plant site and will therefore be accessible by all those approved for site access. It is the Contractors responsibility to protect themselves and their equipment and tools from theft and vandalism as they deem necessary. IPSC will not be responsible for any theft or damage incurred by the Contractor.

Only vehicles owned and insured by the Contractor or an approved subcontractor will be allowed inside the plant fence perimeter. All other Contractor employees shall park their vehicles outside the fence perimeter at Guard Post #1 located southwest of Unit 2. The Contractor shall be responsible for transport of the employees to and from Guard Post #1 and the jobsite. The Contractor shall not use the back of trucks for employee transport.

All Contractor employees will be given security badges by IPSC and those badges shall be displayed each day to allow admittance to the plant site. All security badges shall be returned to the security contractor when the employee terminates their work at this site. All Contractor vehicles will also receive parking stickers from the security contractor allowing entrance to the plant site. Temporary badges and parking stickers are available for intermittent Contractor employees and vehicles.

9. <u>Receiving, Handling, and Storing</u>: The Contractor shall promptly receive, unload, and place into storage or construction all equipment, materials, and supplies needed for completion of this contract.

   a. Receiving: Upon arrival at the plant site, the Contractor shall examine all shipments for shortages, discrepancies, or damage. They shall prepare a receiving report itemizing the material received and submit it to the Project Manger. All shipping containers shall be clearly marked to identify contents with a packing slip included inside each box and a copy on the outside in a sealed plastic envelope securely attached. The list shall be of sufficient detail to enable identification of contents without opening.

   b. Handling: The Contractor shall be responsible for any damage to equipment and materials while in their custody until final acceptance of the work. The Contractor shall unload all carriers promptly and shall pay any demurrage incurred. Materials shall be handled with due care to prevent damage or loss.

   c. Storage: All equipment, materials, and supplies not immediately incorporated in the work shall be placed in storage. Storage areas will be allocated and assigned by the Project Manager but, will be in the general area of the work. The storage areas shall be kept clean and orderly at all times.

10. <u>Disposal of copper and other materials</u>: All removed copper and other metals from the generator shall remain the property of IPSC. The Contractor shall dispose of the removed materials in separate containers for scrap metal that will be provided by IPSC.

PART F - DETAILED SPECIFICATIONS

DIVISION F3 - GENERATOR REWIND DETAILED DESIGN REQUIREMENTS

1. General: This division contains the general requirements for design, fabrication, materials, and factory testing for replacement stator bars for the Unit 1 (T150) generator.

2. Codes and Standards: The applicable sections of the following codes and standards shall be followed during the execution of this work:

    a. IEEE Standard 286 - Recommended Practice for Measurement of Power Factor Tip-Up of Electric Machinery Stator Coil Insulation.

    b. IEEE Standard 1434 - Trial-Use Guide to the Measurement of Partial Discharges in Rotating Machinery.

    c. IEEE Standard C50.12 and C50.13 - Standard for Cylindrical-Rotor 50 Hz and 60 Hz Synchronous Generators.

    d. IEEE Standard 1043 Recommended Practice for Voltage-endurance Testing of Form-wound Bars and Coils.

3. Current Generator Design: The current generator design capability is shown in Table F3-1. A cutaway sketch of a typical stator bar in shown in Diagram F3-1 and the winding connection sequence is shown Diagram F3-2.

4. Generator Design After Rewind: The Contractor shall indicate in their proposal what capacity and efficiency improvements will be achieved as a result of the rewind.

5. Materials: All parts and materials furnished for work in accordance with these specifications shall be new, unused, and undamaged. All parts and materials shall meet or exceed specifications for original parts and materials used in the generator. All parts and materials shall be compatible with original parts and materials used in the generator.

    a. Stator Bars: The stator bars shall be Oxygen-Free Copper or equivalent to reduce the possibility of hydrogen embrittlement and improve brazing. The material selection shall be such to eliminate water leaks in the braze joints. The design shall include Roebel transposition to cause all strands to share the load current equally and minimize circulating current losses within the bar. The bars shall maximize efficiency through the design of the bar configuration.

    b. Insulation: The insulation system material shall be selected to withstand the winding operating temperatures and mechanical forces. It shall also have a high bonding strength to prevent de-lamination due to thermal and electrochemical forces acting on the conductors.

(1) Strand Insulation: The strand insulation material shall be selected to withstand the winding operating temperatures. It shall also have a high enough strand-to-strand bonding strength to prevent strand-to-strand de-lamination due to thermal and electrochemical forces acting on the conductors.

(2) Groundwall Insulation: The groundwall insulation system shall have sufficient dielectric strength and stability to withstand normal line-to-ground operating voltage as well as moderate transient over voltages. The groundwall insulation may be applied as a continuous tape by automatic machine wound over the entire length of the bar to achieve constant pressure pull with consistent overlap. Regardless of the method used, the Contractor shall ensure compact insulation with minimum void development.

c. Wedging System: The wedging system shall be designed to minimize stator bar and core abrasion during normal operation. The wedging system shall also be designed with a re-tightenable end-wedge system to allow re-tightening of the wedge system should looseness occur. The wedging system shall be oil-resistant and capable of withstanding the operating temperatures of the generator with no loosening or deterioration.

d. Temperature Devices: The temperature devices shall be dual element RTD's between the top and bottom bars in each slot and thermocouples in the water headers.

6. Stator Bar Fabrication: The following shall apply to the bar fabrication:

a. The Contractor shall serialize each stator bar so that all material lots, supplier, and quality control tests can be traceable to an individual bar.

b. Technician performing the brazing of the end clip to the strands shall be certified.

c. The brazing shall be done in such a way as to prevent porosity.

7. Quality Control and Testing: A stringent quality control testing program shall be utilized in the fabrication of each of the components. A description of the quality control program that will be utilized showing each step of fabrication and the test performed shall be provided by the Contractor. This description shall include, as a minimum, the following components and a report shall be provided showing the quality control provided on each of the components:

a. Dimensional Checks.

b. Strand Continuity Testing.

c. Strand-to-Strand Isolation Testing: Before water boxes are installed.

d. End-to-End Surface Resistance Measurement.

e. Power Factor Testing.

f. Partial Discharge Testing.

g. High Potential.

h. High Voltage Endurance Testing: Test shall be done at three (3) times rated voltage for one (1) minute.

i. Pressure Test: Tested at a minimum of 100 psi and show no leakage over a one (1) hour period.

j. Final Flow Test: Using dry nitrogen or equivalent.

k. Results of each of the above tests are to be documented for each stator bar and provided to IPSC for review following manufacture.

l. Contractor shall assure that appropriate witness points are included in the manufacturing schedule and they shall advise IPSC at least 30 days prior to each witness point. IPSC will have the ability to enter the Contractor's fabrication facilities at any time to witness a test or fabrication.

TABLE F3-1

CURRENT GENERATOR DESIGN AND OPERATING INFORMATION

Manufacturer:	General Electric
Serial Numbers:	Unit 1: 280T150, Unit 2: 280T151
Generator Rating:	991 MVA
Operating Rating:	950 MW
Generator Type:	2 Pole 60 Hz, Y Connected for 26 kv
Speed:	3,600 rpm
Stator Cooling:	Water, Single Pass
Field Cooling:	Hydrogen Gas, 63 psig
Excitation:	585 Volts, 3,330 KW, EX2100
Stator Amperes:	22,006
Field Amperes:	5,363
Power Factor:	0.90
Year Began Operation:	Unit 1: 1986, Unit 2: 1987
Stator Winding:	36 Slots, 2 Circuits
Stator Insulation:	Micapal II
Support System:	Tetraloc
Blocking:	Textolite
Ties:	Glass Roving
End Windings:	Sausages, Z-Rings, Inner Axials
Series Loop-Type:	Liquid Cooled
Wedge:	Piggyback
Side Springs:	200 Mil
Bushing Cooling:	Hydrogen Gas
P Bar Cooling:	Water

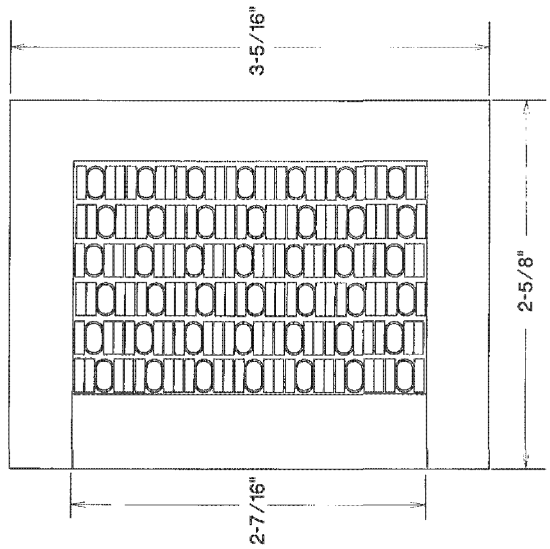
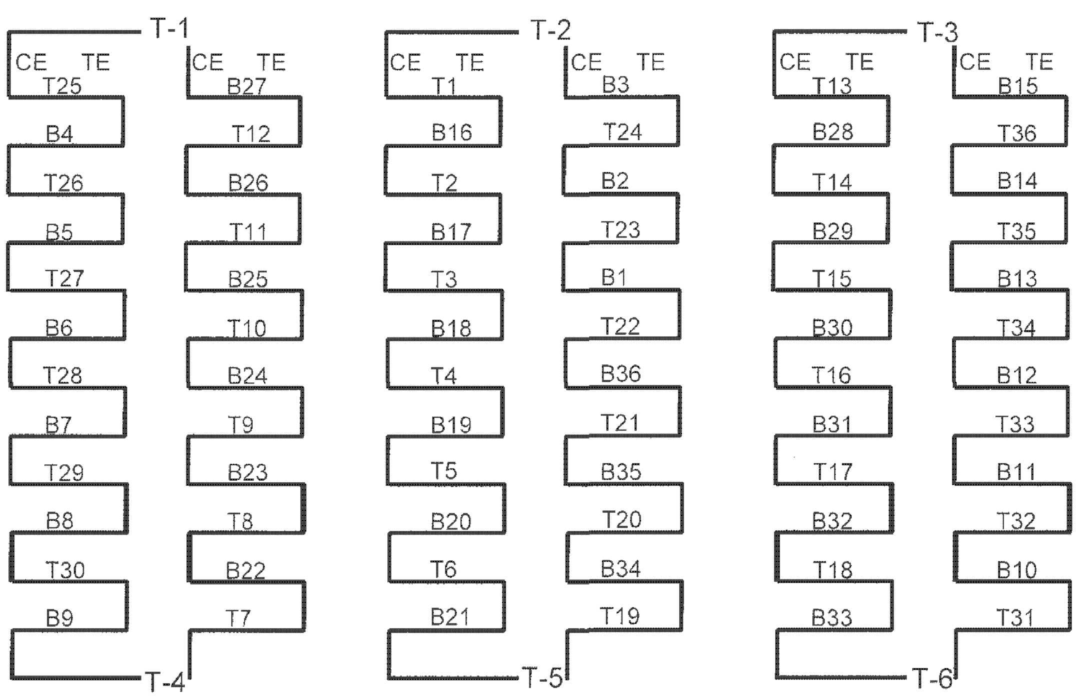


Diagram F3-1 - Cutaway Sketch of Stator Bar Clip-to-Strand Joint Area. Measurements are approximate.

As shown, stator bar consists of six columns of strands. Each column contains seven hollow strands and 21 solid strands. Hollow strands are staggered from column to column.

STATOR WINDING SEQUENCE DIAGRAM



NOTE: For stator bars, "T" denotes top bar in slot, i.e. bar closest to rotor. "B" denotes bottom bar.
Cooling water flows from collector end to turbine end, single pass.
P Bars are in slots 6, 18, and 30.

Diagram F3-2 Stator Winding Sequence Diagram

PART F - DETAILED SPECIFICATIONS

DIVISION F4 - GENERATOR REWIND DETAILED INSTALLATION REQUIREMENTS

1. General: This division contains the general requirements for field installation and testing of the Generator Rewind on both units.

2. Codes and Standards: The applicable sections of the following codes and standards shall be followed during the execution of this work:

   a. IEEE Standard 115 - 1995 Test Procedures for Synchronous Machines.

   b. IEEE Standard C50.12 and C50.13 Standard for Cylindrical-Rotor 50 Hz and 60 Hz Synchronous Generators.

   c. IEEE Standard 43 - 2000 Recommended Practice for Testing Insulation Resistance of Rotating Machinery.

3. Qualified Personnel: Contractor shall provide technically qualified and competent personnel to perform the engineering, design, analysis, calculations, stator rewind, testing and other tasks necessary to complete the work. Winder technicians shall be skilled and experienced in rewinding large water-cooled generators.

4. Field Engineer/Technical Director: The Contractor shall provide a Field Engineer/Technical Director at the job site from when the materials arrive on-site through the completion of the work. Each shift working on the rewind of the generator shall have a competent and experienced Field Engineer/Technical Director to direct the work and provide quality control.

5. Equipment: All test equipment, tools, and other equipment shall be in good working order. Contractor shall provide IPSC with a list of equipment and tools brought to the IPP job site. Equipment which is normally subject to periodic calibration shall be calibrated within the equipment manufacturer's recommended calibration interval. Calibration certificates clearly identifying the most recent calibration date shall be reviewed with the IPSC Quality Assurance (QA) Engineer.

6. Work Practices: Contractor shall ensure that no tools, materials, parts, or foreign objects remain in the generator or generator systems after the work is completed. Contractor shall prevent foreign objects from entering piping, cavities, or other tight spots. Contractor shall have means of controlling access to the generator during the work and for logging all tools and equipment that enters the generator to make sure that it is removed after the work is completed.

7. Temperature Monitoring: The following temperature monitoring shall be installed on the generator during the rewind:

a. Winding RTD's: One dual-element RTD shall be installed in each stator slot with new cable routed from the RTD to the penetration in the stator frame. In addition, new stator frame penetration sealing glands for the cable shall be provided and installed.

b. Discharge Water Temperature: One discharge water thermocouple per stator slot shall be installed with cable routed from each thermocouple to the penetration in the stator frame. In addition, new stator frame penetration sealing glands for the cable shall be provided and installed.

c. Tagging Compounds: The stator core shall be painted with a "tagging" compound in accordance with the original construction for identification of hot spots in conjunction with the existing core monitor. The Contractor shall supply information on the compounds used and how to identify them in the event hot spots do occur.

8. Insulation: All stator winding components and connections shall be insulated to the full phase-to-phase voltage rating of the machine.

   a. There shall be no bare or exposed copper in the completed winding.

   b. Insulation shall be resistant to oil and water.

9. Corona shielding: The stator slot section shall be corona shielded by conductive paint or armor tape to suppress slot discharges under high voltage conditions. A corona suppression gradient shall be applied to the stator bar end arms and connection rings.

10. Wedges: The winding shall be designed so that the coils are adequately supported and braced to minimize radial and lateral movement and to withstand all forces developed under electrical fault conditions.

   a. Semi-conductive side filler shall be used to provide positive pressure on the stator bars as necessary to prevent vibration, sparking, and slot discharges.

   b. The new stator winding wedges are to be assembled tight and shall not have detrimental mechanical resonance. Contractor shall verify this by testing.

   c. Stator wedge materials shall not be of a material that can abrade the stator core iron.

11. End Windings: The stator end winding support system shall be of a proven design that allows movement in the axial direction but provides constraining support in the radial and lateral directions.

12. Cleaning of Slots: The Contractor shall be responsible to clean the slots of the core prior to installation of the new stator bars. The methods used by the Contractor for slot cleaning shall minimize damage to the core.

    a. After cleaning the slots, the Contractor shall perform another Core Loop Test to determine what damage, if any, was done to the core during disassembly of the stator bars and cleaning.

    b. All core damage found during this test and not found during the initial test shall be assumed to be caused by disassembly and cleaning and shall be repaired by the Contractor at no expense to IPSC.

13. Core Integrity Test: The Contractor shall test the core for integrity prior to installation of the new stator bars. The Contractor shall repair all problems found during the core integrity test on a Time and Material Basis.

14. Quality Control: It is the responsibility of the Contractor to develop and implement their own quality control plan as necessary to complete a quality job. The plan shall contain progressive testing during the rewind to eliminate marginal or weakened insulation and provide a reasonable assurance that the winding will pass the Final Acceptance Test. The plan shall contain, as a minimum, the following test procedures:

    a. Over-potential testing of each bar after side packing in the slot at 125 percent of the final test value. This testing can be done in groups, as the work progresses, as convenient for the Contractor.

    b. Over-potential testing of each bar after wedging of the bars in the slot at 120 percent of the final test value. This testing can be done in groups, as the work progresses, as convenient for the Contractor.

    c. Temperature detectors shall be tested for correct function prior to insertion and with over-potential after the slots are fully wedged.

    d. Any bar that fails over-potential testing shall be removed from the generator and replaced with a new bar. Repairing of a failed bar is not allowed. The Contractor shall immediately perform a destructive analysis of the failed bar to determine the cause of the failure and shall report the cause of the failure to IPSC prior to Final Acceptance Testing.

    e. The Contractor shall work with IPSC to develop procedures for all over-potential testing that will insure the safety of all personnel, and that will be in compliance with IPSC's Safety Clearance Procedure.

15. Final Acceptance Testing: The following testing shall be completed to verify that the generator is suitable for service and to verify compliance with the requirements of this Contract:

a. Final Over-Potential Test: This test shall be performed after winding assembly and just before the final paint is applied. The test shall be done at twice the rated voltage plus 1000 ($2V_L$ +1000) AC with all three phases separated from each other at the neutral connection.

b. Stator Winding Resistance: Each resistance reading shall be corrected to 25º C.

c. Temperature Element Over-Potential: The test voltage shall be 2,500 VDC for one minute.

d. Temperature Element Function.

e. Insulation Resistance: The test shall be completed on all three phases individually, with the other two phases grounded. Microamp and megohm readings shall be taken every 30 seconds throughout the 10 minute test period. The test voltage shall be 2,500 VDC.

f. Partial Discharge.

g. Power Factor Test (Doble).

h. End Turn Frequency Response Test (Bump Test).

i. Wedge Tightness Test.

j. Pressure Decay Test: Pressure decay test shall start at 70 psig. Test pressure shall be allowed to stabilize. Generator winding temperature shall be measured in a least six (6) places: (2) two at the inlet heater, (2) two in the core, and (2) two at the drain header. The temperature used for test calculations shall be the average of the six (6) readings. Temperature and pressure shall be measured within 0.1º C and 0.1 psi respectively. Once the pressure and temperature are stable, the generator shall be isolated from the pressure source. Pressure readings shall be taken every hour for at least 24 hours. The leakage rate shall be calculated and reported to IPSC. Pressure decay test leakage limit is one (1) cubic foot per day.

k. Vacuum Test: The vacuum decay test shall start at or below 100 microns. The generator shall be isolated from the test skid and vacuum level shall be recorded every five (5) minutes for one (1) hour. The vacuum leakage rate shall be calculated and reported to IPSC. Vacuum decay test leakage limit is three (3) cubic feet per day.

l. Any other baseline testing recommended by the Contractor.

16. <u>Capacity and Operating Temperature Verification</u>: Prior to final acceptance of the work, IPSC will conduct a 24-hour test run of the machine at the new stator rated capacity. Measurements of generator performance and temperature will be recorded throughout the test to verify compliance with the curves submitted during the bidding process.

Original HP Turb specs

Part F - Detailed Specifications

Division F2 - Technical Requirements

1.0 General:

This specification provides the technical information required for providing both products and services associated with supply and replacement of the high pressure turbine sections, overhaul of the intermediate pressure turbine, internal alignment of these two sections and technical direction services for effectively completing all turbine work scheduled for both the March, 2003 Unit 1 Outage and the March, 2002 Unit 2 Outage at the Intermountain Generating Station (IGS).

2.0 Unit Description:

Intermountain Generating Station consists of 2 sister units operating S-2, triple tandem-compound, single reheat, 20- stage, impulse type turbines with a double-flow nozzle. The high pressure turbine is a partial arc design with 7 stages and one, 4th stage extraction. The turbine is controlled via a Mark II series electrohydraulic system.

The turbines have been increased in nominal output rating from an original installation output of 840 MWg to a current rating of 875MWg.

3.0 IPSC Planned Turbine Scope of Work:

The planned scope of work for the turbine generator during the Unit 2 outage beginning March 2, 2002 is:

- Replacement of the HP turbine section
- Major inspection and overhaul of the Intermediate Pressure Turbine section
- Testing and possible disassembly of the generator for repair of stator winding leaks.
- Main stop, control, combined reheat and ventilator valves
- Overhaul of servos, switches and PMG at front standard

The planned scope of work for the turbine generator during the Unit 1 outage starting March 1, 2003 is:

- Replacement of the HP turbine section
- Major inspection and overhaul of the Intermediate Pressure Turbine section
- Testing and possible disassembly of the generator for repair of stator winding leaks.
- Main stop, control, combined reheat and ventilator valves

- Overhaul of servos, switches and PMG at front standard

The above scopes of work are to be provided for each of two units at the Intermountain Generating Station during their respective outages. Bidders are encouraged to respond to the above specified outage start dates if possible. If adherence to the above dates places significant risk in either quality or delivery of the HP turbine section, the bidder may propose an alternate schedule for outage start date. Proposals with modified outage start dates more than 1 month later than those specified above, will likely be untenable.

4.0 Scope of Supply:

The scope of this specification includes the following:

1. Design, manufacture, shop testing and delivery of a new, high efficiency HP turbine section.
2. Field engineering services for on-site direction during installation of the new HP turbine section, overhaul of the IP section, overhaul of control, stop and combined reheat valves, overhaul of front standard servos and instrumentation and testing and operation of the completed turbine as listed in Section 6.0.
3. Field direction of electrohydraulic control system modifications for optimized valve operation including parts as required.
4. Internal alignment services for both the HP and the IP turbines.

5.0 Design Conditions & Criteria

The justification for this project rests on both performance and output. Therefore, all reasonable effort shall be made to identify and incorporate the most current and proven performance related technologies.

IPSC understands that by design, the new, high efficiency HP turbine sections are unable to provide both partial arc and full arc operational modes. Accordingly, IPSC chooses to specify a full arc operational design to take advantage of upper end operating efficiencies.

As a part of the modification to exclusive, full-arc control, the supplier shall provide required hardware and technical support for modifying existing valve operation. The supplier shall ensure that valve control, unit stability and generation flexibility are not restricted, encumbered or complicated beyond current capabilities.

The HP section shall be designed for the following throttle conditions and flow passing capability at valves wide open:

- 2400 psi
- 1000 F
- ????????? lbs/hr

The supplier shall be solely responsible for ensuring that all piping penetrations, instrument taps/wells, interfacing keys and supports, journals, couplings, snout sections, seals, etc. are of proper location and dimension.

Maximum allowable vibration in any plane in the fully assembled and operating turbine is 2 mils p/p, overall reading.

The HP turbine sections provided for installation on Unit 1 and Unit 2 shall be operationally interchangeable in every regard.

6.0 Field Service Engineering

Field Service Engineers shall arrive on-site no later than two days prior to the respective outage scheduled start dates. Field Service Engineers shall be available in accordance with the planned outage shift schedule, from two days prior to the outage scheduled start date, until released by IPSC following successful startup and operation of the turbine.

At least two qualified Field Service Engineers shall be provided, one for the day shift and one for the night shift. The engineers shall perform the following functions:

-Technical direction to IPSC for disassembly, cleaning, inspection, repair, part replacement, reassembly, rotor alignment, balancing, etc. of the steam turbine-generator.

-Assist IPSC with overhaul planning, schedule preparation and schedule updating.

-Prepare, and submit to IPSC, a technical report which details the inspections, repairs, and future recommendations related to the work done on the turbine-generator.

The Field Service Engineers shall have had formal training for field engineering on large, impulse design, steam turbine-generators. The Field Service Engineers shall have at least 10 years of field engineering experience in installation, repair and operation of these type machines.

7.0 Internal Alignment Services

The supplier shall provide labor, supervision, expertise, tools and equipment for full internal alignment of the HP and IP sections of the turbine. Where laser alignment technology is employed the supplier shall test all equipment at his shop prior to mobilizing to the site to prevent downtime due to faulty equipment.

The supplier shall provide adequate numbers of trained personnel in order to judiciously pursue completion of the internal alignment without interruption, during the scheduled alignment window.

Alignment personnel must be able to effectively coordinate all alignment information with the Field Service Engineers at the site, regardless of corporate affiliation. Personnel conducting turbine internal alignment work shall be trained and qualified in the procedures used and in operation of the equipment required for the work. The personnel shall have performed the same work on at least ten previous occasions, and at least five of those on large, impulse design steam turbines.

8.0 IPSC Provided Facilities

IPSC shall provide a single desk in an enclosed office trailer on the turbine deck for the field engineers to use. The trailer will also be occupied by IPSC personnel.

IPSC shall provide a single telephone line in the office trailer for use by the Field Service Engineers.

IPSC shall provide access to a fax and copy machine for use by the Field Service Engineers.

9.0 Reference Drawings

-Original acceptance heat balance (Figure 1)
-Current heat balance (Figure 2)

10.0 Operating Experience

Intermountain Generating Station has operated for the past 5-6 years with net capacity and availability factors in excess of 90%. Net output in excess of 95%.

Weekly valve and yearly tightness and overspeed testing has been successfully completed since original installation.

Turbine startups have been relatively smooth on both units. Only rarely is a balance shot required during startup.

On-line vibration is rarely above 3 mils p/p on any bearing. With continuous vibration archiving and trending capability, actions levels are based both on rates of change and on absolute vibration levels.

A load profile (Figure 3), typical of recent years is enclosed for your information.

11.0 Maintenance History and Provisions

The Intermountain turbines were overhauled completely by the OEM, on one occasion approximately 2 years after commercial operation. Since that time all maintenance on the turbines has been performed by IPSC personnel under the direction of a Field Service Engineer.

Turbine oil is monitored by on-site, predictive maintenance personnel who are fully trained in ferrographic, particulate and inductively coupling plasma analysis. The turbine oil was recently replaced on both units as the oil additive packages were showing signs of degradation affecting the oil/moisture separation properties. However, moisture has remained continually within allowable limits.
IPSC is aware of no dimensions affecting the installation of a new HP that have been modified since installation. The only significant modifications to the turbine since startup are follows:

- Hydraulic Coupling Bolts, (Ovako, Inc.)
- Retractable Packing, (Turbocare, Inc.)

The IPSC turbine bay crane is rated at 95 tons.

12.0 Manufacturing Schedule

Within six weeks of award, the supplier shall submit a detailed schedule showing all facets of completion of the HP turbine section and associated components. The schedule shall include:

- Order placement for material stock for each major component
- Expected delivery to manufacturing facilities of stock for each major component.
- Start of material acceptance testing for each major component
- Start of manufacture of each major component
- Start of shop testing for each major component
- Start of component sub-assembly, (i.e. rotor assembly, diaphragm assembly, etc.)
- Start of sub-assembly testing, (i.e. rotor testing, diaphragm NDE and final dimensions)
- Start of assembly (alignment, etc.)
- Final assembly dimensional verification

Updated manufacturing progress reports shall be prepared and submitted to IPSC on a monthly basis up to the date of final inspection and shipment. In addition to updated manufacturing and testing schedules, the supplier shall provide notification of testing identified by IGS as 'witnessed tests' in Section 17.0, 'Quality Assurance', at three separate intervals prior to the day of the test in order to allow for IGS travel arrangements:

- 30 days prior to the test
- 14 days prior to the test
- 7 days prior to the test

The supplier shall provide construction drawings for approval by IPSC prior to start of fabrication. Required approval date shall be clearly identified at the time of construction drawing submittal to IPSC. Approval of construction drawings shall not relieve the supplier of sole responsibility for proper design and manufacturing accuracy and quality,

13.0 Delivery Schedule and Incentives

The Unit 2 HP turbine section and associated components shall be delivered at the IGS facility no later than February 18, 2002.

The Unit 1 HP turbine section and associated components shall be delivered at the IGS facility no later than February 17, 2003.

For delivery of the HP section to the site two (2) weeks ahead of the outage start date the supplier will be allowed to avoid two days of penalty beyond his guaranteed installation schedule prior to any penalty being assessed. This means that with delivery two weeks ahead of the scheduled outage date, the maximum outage extension penalty will be reduced to $800,000 and will not begin accumulating until two days past the guaranteed installation schedule identified within the bid.

For delivery to the site after 12:00 midnight on the respective IGS delivery dates noted no early payment shall be made.

For delivery after March 1, 2002 for Unit 2 or after February 28, 2003 for Unit 1, a penalty of $200,000 will be assessed to the supplier to assist in paying for rebuild of the existing HP turbine section.

14.0 Installation Schedule and Incentives

IPSC is encouraging base and alternate bids that key on innovative methods for minimizing installation schedules while maintaining verifiable installation quality. The respective outages have a currently scheduled nominal length of 30 days. This 30 day schedule is defined as 'Breaker Open' to 'On-Line and Available for Full Load'.

All bidders shall prepare a 'guaranteed' installation schedule for the HP turbine replacement. The bid outage schedule for replacement of the HP turbine section shall provide detail from 'Breaker Open' to ' Turbine on Turning Gear'. The current maintenance schedule shows this as approximately 28 days.

The bid schedule shall include task level detail for removal of the existing HP section, field accommodation work within the existing HP shell and full installation of the new HP section including alignment. Major milestones shall include as a minimum:

- New HP components staged and ready for installation
- Turbine off gear and lube oil isolated
- Removal of HP outer shell
- Removal of HP rotor
- Removal of HP L/H casing
- Completion of L/H outer shell prep work and dimensional verification
- L/H casing installed
- Alignment complete
- Rotor installed
- U/H casing installed
- U/H outer shell installed
- HP installed and coupled

The current maintenance schedule is based upon a dedicated, HP turbine section crew consisting of 6 maintenance mechanics working 2 each 10 hour shifts per day, 6 days per week.

For each day that the outage length is extended due to the supplier's products or actions or the direct installation requirements of the new HP turbine section, the supplier shall be assessed a penalty of $100,000. The penalty maximum assessed for outage extension shall be 10 days or $1,000,000.

If the turbine section is delivered late and IPSC elects to proceed with installation of the new HP turbine, no outage extension penalty shall be assessed unless and until the suppliers bid installation schedule is exceeded due to the suppliers products, actions or direct installation requirements.

At least 90 days prior to the respective scheduled outages the supplier shall have a coordination meeting with IPSC Outage Management and prepare a complete installation information package based on the specific approach and schedule selected by IPSC. This final detailed schedule shall be provided to IPSC within 10 working days of the coordination meeting and shall provide completely detailed sequential instructions on installation and alignment of the HP section, including any modifications to existing HP section hardware, special tooling, equipment or services that may be required.

Both the outage schedule and duration are subject to change by IPSC. In the event of any IPSC initiated schedule change, IPSC will immediately notify the supplier and negotiate a mutually agreeable resolution.

The supplier shall identify within their prepared outage schedule, any interface concerns with the simultaneous overhaul on the IP turbine including bearing type/composition and positioning, coupling alignment, etc.

15.0 HP Section Performance Testing:

Initial performance testing shall occur as soon after the outage as reasonably possible. IPSC anticipates the ability to complete the initial performance testing within 1-2 weeks of startup. However, several factors could develop that could delay the test, these factors include an inability to achieve stable or acceptable turbine vibration limits, lack of permission from dispatch authority, unforseen load demands or problems with other plant equipment.

In addition to initial performance testing, IPSC will complete a confirmation test approximately 30 days following initial performance testing. Performance incentives/penalties shall be calculated and awarded based on the average of the initial performance test and the 30 day confirmation test.

The supplier is invited to be present during all testing. IPSC will apply best effort to confer with the supplier regarding all issues that may affect the evaluated performance of the turbine.

IPSC will prepare a specification and engage a qualified contractor for the performance tests. For general information the following criteria will form the basis of the performance testing:

1. The unit shall be operated at steady state, full load for approximately 1 hour prior to start of test.
2. Steady state shall be defined as fluctuations of not greater than:
   - 1.0% of absolute pressure readings
   - 5.0 degrees F, temperature readings
3. Test shall consist of a minimum 60 minute test, with readings taken a minimum of every 2 minutes.
4. Target testing criteria shall be throttle flow of ??????lbs/hr @ 2400 psi throttle and MWg output of ???????.

Testing tolerance for all forms and all sources of testing uncertainty shall be 0.25%. This is based on the following testing accuracies:

- 0.1%, throttle pressure
- 0.1 psi, HP exhaust

- 0.5 degrees F, all temperatures

All readings shall be taken at two parallel points allowing for direct indication of faulty equipment. Both elements shall be monitored and recorded during the equalization period and throughout the performance test for increased accuracy. All testing instrumentation shall be calibrated and traceable to NBS Standards. Instrumentation shall be calibrated both before and after testing is complete.

The cost of one initial performance test following the outage and one confirmation test approximately 30 days subsequent, will be borne by IPSC. All testing shall be considered valid and contractually binding if the HP section efficiency is tested to be no more than 2.0 percentage points below design efficiency.

If the measured section efficiency, during either the initial performance test or the 30 day confirmation test is more than 2.0 percentage points below design, an additional test shall be run and paid for by IPSC, as soon after the first test as operationally reasonable.

If the first test is within the 2.0 % window or if the second test is outside(below) the 2.0% window, the first test results shall be valid and contractually binding.

HP section efficiency shall be defined as measured across both the valves and the HP section; from throttle conditions to the HP section exhaust.

16.0 Performance Guarantees and Incentives:

****

TO PURCHASING: THIS COULD GO IN A COMMERCIAL SECTION

Bidders shall be awarded a bid evaluation credit (not payable dollars) of $10,000 for each 0.1% in HP section efficiency, above 91%, that is guaranteed in the respective bid.

Bidders shall be awarded an evaluation credit (not payable dollars) of $50,000 for each megawatt of generation capacity above ??????????? MW at VWO, 2400psi throttle, guaranteed in the bid.

****

Supplier shall be penalized ????????? if throttle flow at VWO, 2400psi exceeds 6,975,000 lbs/hr. This penalty covers near term reduced pressure operation and required system modifications.

The supplier shall be awarded a cash incentive of $10,000 for each 0.1% in performance that is confirmed by the performance test results above 92%, up to a maximum performance cash incentive of $100,000. No testing tolerance shall be applied above 92% prior to calculating the performance incentive.

The supplier shall be penalized $10,000 for each 0.1% below guaranteed HP section efficiency that is confirmed by the performance test results, up to a maximum penalty of 100,000. This penalty shall not take effect until after the 0.25% testing tolerance has been applied.

The supplier shall be awarded a cash incentive of $50,000 for each Megawatt of generation in excess of the bid guarantee that is proven during the initial and 30 day confirmation performance testing, up to a maximum of 5 Megawatts or $250,000.

The supplier shall be penalized $50,000 for each Megawatt of generation below the bid guarantee output that is confirmed during the initial and 30 day confirmation performance testing, up to a maximum penalty of $250,000.

17.0 Quality Assurance:

Vendor shall implement a quality assurance program addressing all phases of design, manufacture, installation and startup of the HP turbine section. The purpose of the HP section Q/A program is to assure that:

1. Design documents, drawings, specifications, quality assurance procedures, inspections procedures and purchase documents are maintained current, accurate and under control.

2. The purchased materials, equipment and services conform to the requirements of these documents.

3. Receipt inspections, in-process inspections, examination and testing are complete and appropriate.

4. Subcontracted work is adequately inspected and monitored.

5. Special processes such as welding, heat treating, hot forming and NDE are of adequate quality

6. Welders and NDE personnel are adequately qualified.

7. Nonconforming equipment and materials is properly documented, controlled and dispositioned.

IGS shall have full access, at all times, to the quality assurance procedures, instructions and nonconforming reports applicable to the equipment and materials furnished under this contract.

The quality assurance manual shall include the manufacturing locations of each major component, all tests to be performed on each component and assembly and shall list the individuals with respective phone numbers that will be in charge of quality verification at each site.

The supplier shall, as a minimum, provide for the following levels of documentation, review and acceptance of quality assurance procedures and reporting on all major components including the following:

1. Rotor
2. Buckets
3. Diaphragms
4. Inner Casing
5. Inner Casing Bolts
6. 1^{st} Stage Nozzle

(Test Definitions Note:

Witness: The test may be attended by an IPSC representative
Review: IPSC shall review the test results prior to start of mfg.
Copy: IPSC shall receive signed copy of the test results within 1 week.)

	Witness	Review	Copy
Chemical/Mechanical Properties			1,2,3,4,5,6
Mill Certifications			1,2,3,4,5,6
Heat Stability Testing			1
Non-destructive Testing (Incl. welds and castings)		1,2,3,4,5,6	
Dimensional Checks	1,2,3,4,5,6		
Balance/Overspeed Testing		1	
Final Shipping Inspection	1,2,3,4,5,6		

Additional examination or testing may be required by IPSC of any welds, castings or forgings with indications exceeding code allowables or those having been or requiring repair.

Where designs incorporate sectionalized rotors, the root welds shall be examined using MT methods. Final passes shall also examined using MT and shall examined using UT from three angles of maximum reasonable variation.

18.0 Bid Submittals:

In addition to any other requirements of these specifications, the supplier shall provide the following information with the bid submittals:

1. A list of all components provided, with mfg. part numbers and including component life expectancy.
2. Balance criteria to be imposed by supplier .
3. Estimated Shipping Weight and Installation Weight of assembled HP
4. Detailed explanation of methods and equipment to be used in performing turbine internal alignment.
5. List of any additional items which the contractor will need IPSC to provide, other than those listed in Section 8.0.
6. Resume and experience list for each field service engineer, technician, or other personnel to be involved in the IGS based portions of the work.
7. Detailed plan for any on-site inspection work that must occur in advance of the installation, including the upcoming Unit 1 outage beginning March 5, 2001.
8. A best approximation schedule for completing the following major milestones: (to be shown in multiples of 10 hour shifts using up to 6 trained turbine mechanics)

-Old casing out
-New casing on final shims
-Rotor Aligned in bearings
-HP reassembled

9. A list of any special tools required for installation or maintenance of the new HP section. Including balance weight placement or casing guide pins.
10. A list of recommended spare parts associated with the HP section. The list shall include estimated life of each component and location/quantity of any supplier warehoused stock of each item.
11. Applicable section of each code and/or standard used in development and design of the HP turbine section including:
    ASTM - Materials Standards
    ASME - Performance and Construction Standards
    AISI - Material Standards
    ISO - Balance Standards (or applicable international standard)

19.0 Contract Document Submittals:

During the course of fabrication of the HP section, the supplier shall expeditiously submit the following information in accordance with the monthly updated, manufacturing schedules and reports outlined in Section 12.0:

1. Construction/fabrication approval drawings
2. A revised thermal kit based on the throttle conditions
3. Ongoing Q/A reports as specified in Section 17.0
4. Mill Certificates
5. Manufacturing progress reports
6. Rotor Balance Report including static unbalance at critical speeds and rated speed
7. Rotor Runout Report
8. Calculated Rotor Torsional Characteristics
9. Assembly and Interface Dwgs
10. Component and assembly rigging plan including accurate weight of each lift.
11. Piping connection and instrumentation port location drawings
12. Within 30 days after award the contractor shall submit a schedule of submittals including all drawings, by title and their estimated submittal and approval return dates.
13. Itemized list of each component type showing individual design weight.

20.0 Existing HP Section Availability

The existing, Unit 1, HP turbine at IGS is currently scheduled to be available for inspection, measurement and condition assessment during the upcoming outage currently scheduled to begin March 5, 2001. The following items are scheduled to be completed at that time:

1. The upper half HP section outer shell will be removed.
2. The 4th stage extraction line will be severed and drifted to allow access from the outside.

If the bidder desires to take advantage of this inspection opportunity, the bidder shall prepare and provide a detailed inspection plan along with the bid submittals as outlined in Section 18. The plan shall include the significant, foreseeable economic or schedule impacts that may occur as the result of the information to be gathered during the outage.

The successful bidder shall have up to four (4) days of access for inspection of the HP turbine on Unit 1. **The HP turbine inner casing will not be open.**

21.0 Shipping

All components and assemblies shall be packaged, coated, supported and secured to prevent corrosion, damage or deformation during shipping. Any damage sustained prior to delivery at the IGS facility shall be judiciously corrected by and to the account of the supplier.

Bearing journals areas shall be securely covered and protected by treated cotton cloth or acceptable equal to prevent inadvertent contact or corrosive elements.

22.0 Maintenance Manuals

The supplier shall provide 10 sets of maintenance manuals at time of delivery, including the following information:

- Detailed overhaul recommendations
- General Arrangement Dwgs.
- Rotor Clearance Drawings
- Diaphragm Alignment Dwgs
- Longitudinal X-section Elevation
- Shaft Torque Characteristic Plot

23.0 Warranty

Due to IPSC outage schedules, the supplier's warranty must extend at least two years beyond installation in order to verify the cause of and correct any significant efficiency reductions. Due to operational priorities, access to turbine components for warranty adjustments shall be at the discretion of IPSC.

IPSC shall retain the right to operate the components and equipment provided under these specifications regardless of any outstanding warranty issues. The supplier shall be released from any additional claims for damage incurred as direct result of such continued operation. Warranty obligations for defects not attributable to such continued operation shall remain the responsibility of the supplier.

Supplier shall provide schedule identifying any maintenance procedures or testing/inspection required to maintain the bid warranty provisions.

Bid Totals

		Unit 1(2003)	Unit 2(2002)
1.Price for Fully Assembled HP Turbine Section			
2.Price for Aligned /Partially Dis-assembled Section			
3.Price for Freight	(Fully Assembled)		
	(Partially Assembled)		
4.Contract Cancellation Cost:	>16 mo. before ship		
	12-16 mo. before ship		
	10-12 mo. before ship		
	6-10 mo. before ship		
	< 6 mo. before ship		
5. Field Service Engineering (To include all labor, expertise, travel, expenses and services.)			
6. Field Service Engineering Rates for Unanticipated Work Hours:	Regular Hours		
	10-16 Hrs/day		
	Holidays		

Travel time	__________	__________
Expenses/day	__________	__________
7. Turbine Internal Alignment Services (To include all labor, travel, expertise, expenses, equipment and services.)	__________	__________
8. Guaranteed HP Section Efficiency (Measured across both valves and HP section.)	__________	__________
9. Guaranteed Gross Unit Output	__________	__________
10. Price for Optional Retractable Packing (Packing design must be approved by IPSC representative.)	__________	__________
11. Guaranteed Delivery Dates	__________	__________

COMMERCIAL NOTES TO PURCHASING:

The bidder shall a provide a required payment schedule,

All costs associated with any reverse engineering shall be included with the original bid.

A
EXAMPLE OF A TURBINE BUCKET RFQ

This appendix presents an example of a bid package that is designed to solicit a replacement row of blades. In this example, a low-pressure L-0 row is specified. Detailed information required to customize the bid package is identified in brackets, for example, [plant name].

The package is organized into five parts:

- Part 1 establishes the scope of the bid, under whose direction the bid is being conducted, and basic issues or conditions that govern the evaluation, selection, and schedule of the award to a supplier.
- Part 2 provides a format that each response is requested to follow. Providing a format generally makes it easier to compare and contrast the information that is identified as most relevant to the buyer.
- Part 3 gives details on the type and operating conditions for the unit as required to provide potential suppliers with sufficient information to determine if they can offer replacement parts. Part 3 also allows the plant to identify any special issues or concerns associated with delivery, design, or service that are particularly relevant in the final consideration of any bid.
- Part 4 itemizes the technical criteria that are used to control each step of the supplier's process, from selection of materials to installation of the row. As noted throughout the example, this section is designed to use selected technical criteria identified in Sections 1 and 2 of Volume 3 [11] of the *Guidelines for Reducing the Time and Cost of Turbine-Generator Maintenance Overhauls and Inspections* series. If balancing is required as in the example, Sections 1 and 2 of Volume 3 are referenced.
- Part 5 lists a number of ASTM specifications that are relevant to the treatment, composition, design, and manufacture of turbine buckets. These are referenced as basic industry standards that any qualified supplier would be expected to follow.

The last section contains three attachments.
Part 1 is the format to summarize the essential cost elements and conditions of purchase for the bid (referenced under Part 2).
The bidder's proposed schedule for delivery is established in Part 2 with required documentation to be supplied at identified milestones.
Part 3 provides a summary of the technical criteria used to assess and/or accept the quality of work performed under the contract. This attachment provides a form by which final acceptance can be determined by the plant.

~~[EXAMPLE]~~

REQUEST FOR QUOTATION

88/row

176/LP Turb

528/unit

1056/station

? ~~18~~/spares
6

(1-LP Turb)
old Keep 176 2spare sets
in case of emergency

12 Rows, total
REPLACEMENT OF (Row Number) BUCKETS
IGS 1 and 2
FOR PLANT [NAME] UNIT [NUMBER]

Prepared by:

Name

Address

Acting on behalf of:

Operator IPA?

Address

Response Requested by: [DATE]?

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total number of buckets, 12 units, 6 rows,

1. SCOPE AND AUTHORITY

1.1 REQUEST FOR QUOTATION

Defined within this specification are the requirements to supply and install a single row of L-0, (LSB-last stage bucket) buckets for use in the dual flow low-pressure turbines (3, three) of the Intermountain Generating Station, Units 1 and 2, operated by Intermountain Power Service Corporation. The buckets rely on a pinned root ([illegible] type) [~~finger and pen~~] type root-disk attachment design. In accordance to this request, a total of [six rows, of state number] buckets are to be supplied, [including a notch blade and its counterpart for balancing purposes if an axial entry type root attachment design is involved]. [State number] of buckets are to be installed in the row, and five identical buckets are to be supplied as spares.

The supplier of the new row shall be further responsible for (1) disassembly and reassembly of the rotor as required for removal of the old L-0 row, (2) installing the new L-0 row, (3) performing a slow-speed balance of the rotor after installation of the new row, and (4) performing a high-speed balance of the rotor during startup and operation. Removing old buckets and installing new design buckets should be identified as a separate cost from the manufacture of new buckets.

1.2 MINIMUM ACCEPTANCE CRITERIA

1. The new row must be compatible with the existing stationary nozzles and other components within the LP turbine.

2. A grouping or linkage strategy is to be used that ensures the first four fundamental modes of vibration will operate at least 10 hertz from the nearest resonant frequency.

1.3 OTHER CRITERIA

1. The new row of buckets should seek to improve the efficiency of the low-pressure turbine. The supplier shall specify the extent of efficiency improvements, if any.

2. Shot peening/coating should be considered around tie-wire holes, on covers and tenons, on bucket dovetail surfaces, and on the airfoil vane around erosion shields or in areas requiring brazing and welding. The supplier shall specify the areas where shot peening shall be performed, if any.

1.4 WARRANTY AND LIQUIDATED DAMAGES

1. The new row shall be warranted from fatigue or failure for a period of [state] 5 years or [state] 40000 operating hours and [state] 1000 start-stop cycles, whichever comes first.

2. The supplier shall provide for liquidated damages for bucket shipment from the manufacturing facility, on-site delivery to the plant site, and total installation time at the plant site. A bonus for early delivery and installation will be considered.

3. Any bucket that fails to conform to the technical requirements as specified within this package will be replaced at no cost to the purchaser.

1.5 EVALUATION AND SELECTION PROCEDURE

- Interested parties are invited to prepare and submit a response in three parts to this request for quotation (RFQ). Responses should be in accordance with the information as detailed in Section 2.0 of this RFQ and conform to the formats reflected in the section "ATTACHMENTS."
- All responses are to be directed to [Name Contact], who are acting as agents on behalf of [Unit Operator] to establish compliance of the offer with the technical requirements specified within this bid package.
- Bids that offer replacement designs that are considered to be technically feasible will be forwarded to the plant for final selection based on price and delivery.
- Issue of a purchase order will be contingent upon final negotiation of the supplier's claims and guarantees.

1.6 SCHEDULE FOR AWARD

- A replacement row of buckets is being sought for delivery before [state date], to be installed no later than [state date].
- To comply with this schedule, all responses must be received by [Contact] no later than [state time, day, and date] to be considered further.
- A letter of intent to purchase is expected to be issued three weeks after receipt of the quotation.
- A proposed time schedule is supplied in Part 2, with milestones identified. Suppliers are requested to complete this schedule.
- Updates to the final schedule for delivery will be supplied on a weekly basis during manufacture and on a daily basis during installation.

1.7 PROPRIETARY INFORMATION

All information provided in response to this RFQ will remain confidential. No proprietary information is requested to demonstrate compliance with the technical acceptance criteria at this time beyond completion of the checklist in the attachments, Part 2.

1.8 CONTACTS

All quotations are to be mailed to:

[Mailing Address]

Attention: [Key Contact]

Questions regarding the technical contents of this RFQ should be directed to [Key Contact] at [Phone and Fax] or [email address].

2. RESPONSE FORMAT

Responses to this Request for Quotation are to be organized as three parts, relying on the forms that are attached at the end of this document. A response should consist of the following:

- Cover Letter –Contact name and address and request for formal consideration of bid.
- Part 1 – Cost to complete scope as defined in the bid package
- Part 2 – Schedule for deliverables
- Part 3 – Checklist of technical requirements and acceptance criteria

Any issues with stated requirements should be noted and attached to each respective section.

Part 1 presents a breakdown of the total cost to (1) manufacture, (2) ship, (3) prepare, (4) install and (5) slow-speed balance a row of buckets on the [Plant/Unit Number] turbine-generator, located in [site]. Information in Part 1 should include:

- A firm price for the manufacture of [total number] buckets and all attachment hardware to include notch buckets, oversized buckets, etc. If a titanium notch bucket is to be employed, a normal titanium bucket should also be supplied as a counterbalance. The cost for a total of five six spare buckets is also to be provided as a separate line item.
- A statement as to any necessary labor, tools, and equipment that the supplier requires for removing, cleaning, testing, and assembling the buckets and its assembly components. Disassembly and reassembly of the turbine as necessary for bucket removal and replacement will be performed by the supplier. Any other resources necessary for bucket removal and assembly will be provided by the supplier.
- A statement as to any necessary technical support, labor, and equipment required by the supplier to perform the slow-speed and high-speed balance of the low-pressure rotor.
- A rate schedule for any backup factory support (if any) to resolve assembly problems or issues.
- Pricing for any work shall include meals, travel, and other expenses necessary for the work to be performed.

Part 2 is a schedule of milestones and documentation to be supplied at the completion of each milestone. Suppliers are requested to indicate a reasonable timetable. Information in Part 2 should include:

- A detailed schedule or standard checklist to monitor each separate activity to be undertaken on-site, such as, (1) disassembly of the machine/unit, (2) removal of the old row, (3) preparation of the wheel for the bucket assembly, (4) assembly of the buckets, (5) necessary machining and NDE or other tests that may be required, (6) slow-speed balancing the rotor after bucket installation, (7) assembly of the machine, and (8) high-speed balancing the rotor during startup and operation.

- Supplier checklists associated with removal of the old buckets, installation of the new buckets, and slow-speed/high-speed balancing of the rotor shall be provided to the plant contact person prior to leaving the site.

Part 3 is a summary checklist of itemized technical requirements and criteria associated with the purchase of the new buckets. Suppliers are requested to indicate their compliance with these requirements or to offer alternative standards or criteria.

3. BACKGROUND/GENERAL DESCRIPTION OF UNIT

3.1 GENERAL DESCRIPTION OF UNIT

U1+U2 (sister units)

The [XXXXXX Unit X] turbine-generator operates with a live steam of [1250 psi/953°F], is rated at [500 MW], and was manufactured by [XXXXXXXXX]. The unit was commissioned in [19XX]. The present unit trip frequency is set to [58.5 hertz and 61.5 hertz]. Although the unit is rated at [500 MW], it has been operated at 80% load to ~~90%~~ 100 % load ~~throughout most~~ of its operating life. changed w/ Alstom The steam turbine rotor has a single shaft design with [state number] high-pressure (HP) stages, [state number] intermediate-pressure (IP) stages, and [state number] low-pressure (LP) stages. The last stage (L-0) blade is [30"] long. The L-0 blade is designed with a tangential entry three-hook dovetail inserted on the disk by means of a notch. The blades are made of a 12% chromium alloy steel material of the composition and properties conventionally used in steam turbine manufacture. There are [150] buckets in the present L-0 stage with buckets arranged in groups of [five] for a total of [30] groups joined together by a cover band and a loose tie wire. The airfoil section is enlarged at the tie-wire location. The leading edge of the airfoil above the tie wire is flame hardened to reduce water droplet erosion damage. Operating in the Wilson Line, the L-0 blades are subjected to a wet/dry steam environment.

3.2 SIGNIFICANT ISSUES WITH THE PRESENT ROW

In 2000, the unit experienced high vibration and was taken out of service for inspection. It was found that a single L-0 stage airfoil was separated at the tie-wire hole. In addition, inspection revealed seven cracked airfoils at the tie-wire hole. To avoid such a failure in the future, the first four resonant modes should provide a minimum of a 10 hertz margin from the nearest resonant frequency. The erosion shield shall be located on the bucket in a manner to preclude failure from the first four resonant frequency modes.

GE TIL CONCERNS:

EPRI PAPER

4. TECHNICAL CRITERIA

4.1 GENERAL INFORMATION, CODES, AND STANDARDS

1. Upon agreement (verbally or in writing) of intent to purchase a row of buckets, either a sample bucket of the modified design or information describing details of the geometry of the bucket shall be provided by the supplier. This is to allow an independent examination of bucket stresses and resonant frequency modes.

2. Final authorization to purchase the L-0 row shall be received after the independent analysis has been performed, results discussed, and issues resolved with the selected supplier.

3. The latest edition of the codes and standards listed in Section 5, "References," shall be used to establish acceptable criteria that govern the manufacture and installation of the L-0 row.

4.2 BUCKET MATERIALS

1. The bucket shall be manufactured from stainless steel equivalent in composition and mechanical properties to those of AISI 403 stainless steel. Other bucket materials will be considered for the bucket if they have superior properties for the environment in which the L-0 bucket row operates. Covers and tie wires shall be made of AISI 403, AISI 410, AISI 630, or Ti6Al4V titanium alloy materials. Cross-keys shall be made of ASTM A193 Grade material.

2. If buckets are to be forged, they shall be made according to ASTM A314 and heat treated in accordance with ASME A473-80a. If the bucket is to be made of bar stock, the bar stock shall be made according to ASTM A276.

3. Erosion shields shall be made of Stellite 6B material and attached in a manner such that they do not become loose or detach during operation. After fitting, no cavities or hideouts are to be allowed into which corrosive materials may migrate, either during operation or on gear.

4. Test certificates shall be provided for all bucket and attachment parts noted above and shall include material mechanical and chemical properties. Heat treatment charts shall also be supplied if requested.

4.3 PART NUMBERING

1. Brand marks or numbers shall be stamped on the bucket so that the particular melt from which the bucket was made can be identified, and subsequent actions or inspections can be referenced to specific parts. This number shall also be supplied on the moment weight chart.

2. It is preferred for this number/code to be stamped on the exhaust side of the bucket or at a location where it can be seen after installation on the rotor.

4.4 EROSION SHIELDS

1. Erosion shields made of Stellite 6B grade attached by electronic beam welding (EB welded) shall extend down the inlet edge a sufficient length to protect the admission edge from erosion, shall contain no residual stress or stress-sensitive areas that are likely to cause cracks, and shall preserve the aerodynamic form of the bucket.

2. If a brazing process is used, the thickness of the filler strip between the shield and parent material of the airfoil shall not exceed 0.002–0.004" in thickness.

3. The shield shall be sized so that a resonant frequency node point at operating speed does not coincide with the lower end of the erosion shield.

4. X-ray, impact, and/or bend tests shall be performed to test the quality of the shield application. Results will be recorded and reported by part number.

5. Any buckets that are tested and show regions under the erosion shield where there has not been proper fusion will be replaced at no cost.

4.5 SHOT PEENING/SURFACE FINISHES

1. All buckets will be free from deterioration classified as cracks, dents, nicks, missing metal, or corrosion.

2. The final finish achieved in all root fillets will be 64 microinches or better.

3. The final finish on the airfoils of the buckets shall be in the main direction of the steam flow and shall fall within ±70–80 microinches or better.

4. If shot peening or bucket coating is performed, the supplier shall specify the regions where it is to be applied, the procedure by which it is to be performed, and the standard by which it is to be qualified.

5. Any third-party suppliers who are to perform the above work shall be identified along with QA/QC requirements that the supplier will use to ensure that the work is done properly.

4.6 MANUFACTURING CRITERIA

1. Buckets will be checked and verified by the supplier to ensure that the correct radial alignment and pitch is achieved when they are installed on the disk.

2. If required, tie-wire alignment shall be checked and verified by the supplier to ensure that the holes are aligned to within the supplier's acceptable tolerances.

3. Contour profiles shall be checked and verified after the installation of an erosion shield to ensure that any warping or twist is within acceptable supplier standards.

4. Bucket airfoils shall not be welded or hot/cold straightened without written agreement. Any part resized or reworked during manufacturing will be identified by part number and reported as such.

5. Any buckets that cannot be made to reasonably conform to the supplier's standard alignment standards shall be replaced at no cost.

4.7 ROOT AND COVER ATTACHMENT TOLERANCES

1. After manufacture, all pairs of hooks on the root attachment will be properly sized so that the bearing surfaces will match and come into full contact with the counterpart surfaces of the disk hooks during operation.

2. Roots will be properly sized so that no gap exceeding 0.002 inches is allowed to exist between adjacent bearing surfaces prior to unit startup.

3. Sufficient material will be provided to form the tenon head in a manner that will allow the cover band to be fastened tightly to the tip platform such that gaps under the cover band do not exceed 0.005 inches on the inlet edge or 0.003 inches on the discharge side.

4. If an interlocking, integral cover design is involved, the supplier will state the minimum and maximum interference gap size that is allowed between adjacent covers after installation on the disk.

4.8 FREQUENCY TESTING

1. Bucket frequencies will be measured in a room temperature environment. Each bucket shall be securely clamped along the pressure and suction side of the platform. The clamping system itself shall be of sufficient mass to provide a rigid, dynamically inert fixture.

2. The first and second modes of each blade will fall within ±2% of the mean target frequencies, to be identified by the supplier prior to testing. The third and fourth modes of each blade will fall within ±5% of the mean target frequencies.

3. Results of the frequency tests will be referenced and reported by part number. The same information shall be supplied for all spare buckets.

4. Any bucket that fails to fall within the specified range of acceptable frequencies will either be reworked or replaced at no cost to the buyer.

5. A part number will identify any bucket that is reworked to achieve the required frequencies, and details of the work performed will be reported.

6. Results of on-site frequency tests (if required) shall be provided to the plant along with the acceptance criteria for such tests.

7. Upon issuance of a letter of intent to purchase the [L-0] bucket row, the selected manufacturer shall supply a copy of Campbell diagrams from telemetry tests conducted on the L-0 bucket.

4.9 MOMENT WEIGHING

1. After frequency testing, each bucket will be individually moment weighed to establish the arrangement around the rotor that will minimize the out-of-balance forces and field balance adjustments required on the rotor.

2. A moment weight chart shall be supplied for the bucket row and shall include the bucket number, order of assembly, and the moment weight for each bucket being installed with the unit of measure for the moment weight being specified.

3. The same information shall be supplied for all spare buckets.

4.10 SHIPPING OF PARTS

1. Selection of a carrier and arrangements for the shipping of parts will be the responsibility of the supplier. Shipping costs will be in accordance with the contracted price.

2. The supplier will be responsible for replacing any parts lost, stolen, or damaged during the course of shipping parts to the plant.

3. A part number listing and other information required to order the supplied parts shall be provided for the [L-0] bucket row, the individual buckets, and assembly components.

4. A list of units, contact names, and telephone numbers shall also be supplied where such parts are interchangeable.

4.11 PRE-OUTAGE PLANNING SUPPORT AND COORDINATION

1. All drawings necessary to support field installation of the row shall be supplied as part of the order.

2. A list of tools, equipment, personnel, and technical support required by the supplier to disassemble/reassemble the unit, remove old buckets, prepare the wheel for new buckets, install new buckets, and slow-speed/high-speed balance the rotor will be supplied as part of the order.

3. A listing of plant support requirements will also be provided.

4. A checklist or sign-off sheet of inspections and tests to be conducted during bucket removal, wheel inspection and cleaning, bucket assembly, unit assembly and slow-speed/high-speed balance of the rotor shall be provided with the quotation no later than two weeks prior to when work is to begin on-site.

5. Upon arrival on-site, each checklist will be reviewed to verify specific support required of the plant personnel identified by the supplier to complete the activity in accordance with the supplier's schedule.

4.12 REMOVAL OF ORIGINAL ROW

1. Prior to removal of the original parts, notable signs of damage or wear to the L-0 disks will be identified, recorded, and verified with the plant manager.

NDE phased array

2. Upon removal of the original parts, the disk will be cleaned and inspected for any signs of noticeable fatigue, damage or wear. Results of the inspection will be recorded and verified with the plant with recommendations for corrective action, if any, to be immediately provided.

4.13 PREPARATION OF DISK AND INSTALLATION OF NEW ROW

1. Upon completion of the preparation work, results will be recorded and verified with the plant.

2. During installation, checks will be performed to ensure that the roots are properly sized to ensure proper mating between buckets and disk attachments.

3. The row of buckets will be inserted in a way that ensures that adjacent surfaces of the tangential entry roots will achieve a firm and tight interference fit with their counterparts during the process of installation. A tight ring will be in place before the notch blade is installed. The interference drive of the installed row shall be provided as part of any checklist.

4. If a tenon-cover arrangement is used, inspection will ensure that no discontinuities or surface tears are present in the filet radii where the tenon joins the main profile of the airfoil.

5. The individual bucket number will identify any buckets that required bearing surfaces to be machined or resized to meet the specified criteria, and the work performed will be noted.

6. Upon completion of the installation work, results will be recorded on all checklists and provided to the plant.

4.14 INSPECTION OF A NEW ROW

1. If a tenon-cover arrangement is used, the tenon head will have no steps or indentations on its surface after peening.

2. If an interlocking, integral cover design is used, the supplier shall measure and record the interference gap size(s) between adjacent covers after installation on the disk. All gaps will be within specified tolerances.

3. Upon completion of the installation work, results of the final inspection of the row will be recorded and provided to the plant.

4.15 BALANCING

1. The rotor shall be slow-speed balanced in accordance with standard procedures required for the type of balance machine being used.

2. The rotor shall be slow-speed balanced using the factory balance planes. If the factory balance planes are not available, use of field balance planes is acceptable.

3. The rotor shall be slow-speed balanced so that the residual balance in each plane does not exceed a value to be determined in advance by the supplier and verified with the plant. The lowest possible slow-speed balance vibration level is the plant's expectation to ensure minimum vibration during unit startup and operation.

4. When proper slow-speed balancing is complete, proper balance weights (AISI 410 material type) will be installed.

5. Documentation will be supplied to the plant after the slow-speed balancing of the rotor. This documentation will verify that the balancing requirements were met and that the equipment used was sufficiently calibrated to perform the balancing procedure.

6. The rotor shall be high-speed balanced during startup and subsequent unit operation so as not to exceed 3 mils vibration amplitude at running speed and throughout the load range.

5. REFERENCES

ASTM A276	Standard Specification for Stainless Steel Bars and Shapes
ASTM A314-97	Standard Specification for Stainless Steel Billets and Bars for Forgings
ASTM A370-97a	Standard Test Methods and Definitions for Mechanical Testing of Steel Products
ASTM A473-01	Standard Specification for Stainless Steel Forgings
ASTM A484/484M-00	Standard Specification for General Requirements for Stainless Steel Bars, Billets, and Forgings
ASTM A582/ A582M-95b	Standard Specification for Free Machining Stainless Steel Bars
ASTM A751-96	Standard Methods, Practices, and Terminology for Chemical Analysis of Steel Products
ASTM E353	Standard Test Methods for Chemical Analysis of Stainless, Heat-Resisting, Maraging, and Other Similar Chromium-Nickel-Iron Alloys
ASTM E381-01	Standard Method of Microetch Testing Steel Bars, Billets, Blooms, and Forgings

ATTACHMENTS

Part 1- Costs and Conditions of Purchase

Part 2 – Schedule and Documentation

Part 3 – Acceptance Criteria

The following checklists provide a summary of the key issues/items identified within each part of the bid package. After a bid has been accepted, the checklists are intended to act as control documents, recording the plant's formal acknowledgement that the supplier has complied with the conditions accepted with the bid.

Example of a Turbine Bucket RFQ

	PART 1: COST AND GENERAL TERMS/CONDITIONS			
	Please complete the following form. Additional terms or conditions should be attached.			
1	**Cost Breakdown**	Prices in US Dollars		
a.	Manufacturing [state number] buckets and all attachment hardware	$		
b.	Manufacturing [state number] spare buckets with all necessary hardware	$		
c.	Shipping to plant in [state location]	$		
d.	Disassembling/reassembling as required for bucket removal	$		
e.	Installing row	$		
f.	Slow-speed balancing after row is installed	$		
g.	High-speed balancing during startup and subsequent operation	$		
h.	Additional costs: Itemize	$		
	Total			
i.	Bonus/penalty for early delivery	$		
j.	Bonus/penalty for early installation of buckets and unit startup	$		
	Total	$		
2	**Warranty**	Yes	No	
a.	5 years, 40,000 hours, or 1000 start-stop cycles (whichever comes first)			
b.	All liquidated damages from shipment, delivery through installation			
c.	Replacement of any bucket that fails to meet technical acceptance criteria			
	If no to any of the above, reference item number and state exception:			
3	**Minimum Acceptance Criteria**	Yes	No	
a.	Modified design is to be supplied.			
b.	New row is to be compatible with stationary nozzles and components.			
c.	Design includes an erosion shield.			
d.	First four modes of vibration maintain 10-hertz margin from resonance.			
	If no to any of the above, state exceptions:			
4	**Other Features**	Yes	No	
a.	Will the new design provide an efficiency improvement?			
	- If so, indicate what % improvement might be expected.		%	
b.	Is shot peening to be performed?			

portrait

		PART 2: SCHEDULE OF DELIVERABLES AND DOCUMENTATION		
		Using the following list of milestones, please indicate when to expect each could be completed.		
				checkoff
Week		**Schedule for Manufacture, Delivery, and Installation**		**Documentation to Be Supplied**
1	a.	Placement of order		Sample bucket or details of bucket geometry.
	b.	Selection and testing of forging or bar stock materials		Certificate of material mechanical and chemical properties.
	c.	Manufacture of buckets and attachment parts		Part number listing.
	d.	Application and inspection of erosion shields		QC procedure used and results referenced by part number.
	e.	Shot peening/coating/surface finishing of parts		QC process used for shot peening.
	f.	Radial alignment and hole position checks of buckets		Identification of any part (by number) resized or reworked.
	g.	Final inspection of row (buckets and assembly parts)		QA/QC procedures used and results of inspection for each part.
	h.	Frequency testing of individual buckets		Test procedure used and frequencies referenced by part number.
	i.	Moment weighing		List of moment weights and moment assembly chart.
	j.	Shipment of row to site		Selected carrier. Date of shipping. List of parts sent/received.
	k.	Shipment of tools to site		Checklist of tools/equipment provided and those supplied by plant.
	l.	Disassembly of unit and removal of original L-0 row		Checklist of tests and inspections. Disk condition before and after.
	m.	Preparation of disk for new row		Checklist of tests and inspections. Report on final actions performed.
	n.	Installation of new row		Checklist of tests and inspections. Report on final actions performed.
	o.	Inspection of new row		NDE test procedure. Report on results of tests.
	p.	Slow-speed balance of new row and assembly of unit		Balancing procedure. Results compared to agreed-upon criteria.
	q.	High-speed balance of unit during startup and operation		Balancing procedure. Results compared to agreed-upon criteria.
	r.	Removal of equipment		Final report on status of rotor.

Date

Supplier Attachments to Part 2: The following documentation should be attached to Part 2 as part of the bid package:		
	1.	Itemized checklist of activities that supplier will perform to remove the existing row
	2.	Itemized checklist of tests and inspections that supplier will use to inspect and prepare the disk
	3.	Itemized checklist of tests and inspections that supplier will use to assemble and QC the new row
	4.	Itemized checklist of tests and inspections that supplier will use to slow-speed balance the rotor with the new row
		For each activity – removal, preparation, installation, inspection, and balancing, supplier should identify technical support required of plant.

IP7017783

Example of a Turbine Bucket RFQ

PART 3: CHECKLIST SUMMARIZING COMPLIANCE WITH ACCEPTANCE CRITERIA			
The following presents a checklist of requirements and acceptance criteria identified in Section 4 of the RFQ. Suppliers are requested to indicate compliance or non-compliance with these requirements. Conditional changes should be referenced and presented as an attached page to this checklist.			
Compliance			
Yes	No		**Requirement – [Details Presented in Section 4]**
		1	Provide a sample bucket or supply the geometry for an independent examination. (Indicate which.)
		2	Buckets are to be manufactured from AISI 403 stainless steel. (If other, indicate material.)
			Erosion shields are to be manufactured from Stellite 6B material.
			Provide test certificates to show conformance of material and chemical properties.
		3	Parts are to be individually numbered for reference.
		4	Erosion shields shall contain no residual stress and preserve the aerodynamic shape of the airfoil.
			If brazed, the filler strip shall not exceed 0.002" to 0.004" in thickness.
			Resonant frequency node points of fundamental modes are not to occur at the end of the shield.
			Erosion shields are to be tested for proper fusion.
		5	Shot peening/coating is to be performed. (Identify where.)
			Final finish of all root fillet radii will achieve a 64-microinch surface or better.
			Final finish of airfoil surfaces will achieve 70-80 microinches or better.
		6	Radial alignment and pitch are to be checked and shown to be within allowable limits set by the supplier.
			Tie wire hole alignment is to be checked and shown to be within the criteria set by the supplier.
			Warping from erosion shields is to be checked and shown to be within allowable limits set by the supplier.
			No airfoil shall be welded or straightened without written agreement of the buyer.
		7	Roots will be properly sized to conform with disk attachments so that no gap exceeds 0.002".
		8	Gaps under a cover band will not exceed 0.005" on the inlet edge or 0.003 inches on the discharge edge.
			If an integral cover is used, the supplier will state the maximum and minimum allowable gaps at zero rpm.
		9	Bucket 1st and 2nd modal frequencies will fall within ± 2% of the mean specified by the supplier.
			Bucket 3rd and 4th modal frequencies will fall within ± 5% of the mean specified by the supplier. Provide the results from on-site frequency tests if required. Provide the results of telemetry tests performed in a spin pit or from another plant site.
		10	Buckets will be moment weighed and chartered for installation to minimize out-of-balance forces.
		11	Provide a part number listing and other information required to ordered supplied parts.
		12	Provide drawings necessary to support field installation of the row.
			Provide a checklist of tools, equipment, and technical support in advance of all site work. Provide a checklist of tests and inspections to be performed during bucket removal, wheel cleaning and inspection, bucket assembly, and slow-speed balancing of the rotor.
		13	Provide the plant with a report of damage or wear to the L-0 disk before and after removing the buckets.
		14	During insertion, the procedure used will maintain a tight interference fit between adjacent buckets.
			A tight ring of buckets will be in place before the insertion of the notch bucket. The thickness of the notch bucket will be recorded and supplied to the plant.
		15	Inspection will ensure that no tenon heads have steps or indentations on their surface.
			If an integral shroud is used, all gaps between adjacent covers will be checked, recorded, and supplied to the plant along with the acceptance criteria.
		16	Balance the rotor and install proper weights.
			"As left" vibration amplitudes and phase angles along with slow-speed ounce-inch unbalance at each plane are to be reported and verified with the plant.

OTHER CONSIDERATIONS

1. TECHNICAL CRITERIA – ROTATING BUCKETS/BLADES
   - 1.1 Materials, Design, and Loads
   - 1.2 Manufacturing and Processing Criteria
   - 1.3 NDT and QC Criteria
   - 1.4 Non-Conformance
   - 1.5 Schedule for Required Documentation
2. INSPECTIONS AND BALANCING
   - 2.1 Inspection Criteria
   - 2.2 Shaft-System Torsional Resonance Response Criteria
   - 2.3 Low-Speed Balance and Field Balancing
   - 2.4 On-Site Shaft System Balance and Vibration Criteria
   - 2.5 Operating Rotor Dynamic Criteria
   - 2.6 Schedule for Required Documentation

1.2 LIQUIDATED DAMAGES

1. In the event that the LP rotor does not arrive at the site on the agreed-upon date of delivery, the supplier shall pay the plant a penalty at a rate of $XX,XXX per day for each day the rotor is delayed in shipment.

2. In the event that the supplier does not provide the documentation indicated in this specification, the supplier shall pay $X,XXX for each document not supplied.

3. In the event that the supplier does not perform the installation within the specified time period, a penalty of $XX,XXX per day for each day beyond this agreed upon time shall be paid to the plant.

4. In addition to these penalties, if the supplier's replacement turbine fails to meet their guarantees:

- Problems associated with the forging, rotating blades, or stationary components shall be corrected by the supplier at their cost, including the costs associated with opening and closing the unit, for the duration of the warranty period.
- Failure of any portion of the rotor forging, rotating blades, or stationary components that result in downstream damage shall be repaired at the supplier's cost. If a failure or problems occur, the plant and the supplier shall mutually agree to any fix or modification to correct the problem during an outage that is acceptable to the plant.
- The plant shall require the supplier to provide a new forging, new rotating blades, or new stationary components that meet the same criteria provided in this RFQ or those supplied by the part manufacturer if fixes or modifications implemented by the supplier do not resolve such problems, including failure. Rotor dynamic problems or instabilities at running speed, multiples of running speed, or subharmonics of running speed shall be corrected by the supplier at their cost.
- The plant reserves the right to reject any fix or modification if the purchase criteria are significantly impacted. The plant shall require that the rotors be replaced in such circumstances.

1.4 GENERAL RESPONSIBILITIES, COORDINATION, AND REPORTING

1. Prior to the scheduled date presently planned for the replacement outage to begin, the supplier shall be totally responsible for planning, scheduling, training, supervising, and providing the technical support required for the removal of the existing components to the extent necessary to install the new replacement parts.

2. The supplier shall be responsible for necessary labor, tools, equipment, and expendables for the removal of the existing LP components to the extent necessary to install new replacement parts, modify existing parts or systems, start up the unit, and verify that satisfactory rotor balance, rotor dynamic issues, and performance guarantees have been satisfied per the contract or purchase order.

3. Upon acceptance of the bid, this schedule shall be electronically transmitted to the plant contact in a format compatible with MS Project, Suretrak, or other scheduling software that can be used by the plant.

4. During the course of the replacement part manufacturing (to include rotor forging procurement), the schedule shall be updated every two weeks via email with the updated schedule attached to it. The email shall indicate if the schedule has changed, the number of days such changes may be, and the reasons for such changes along with any changes regarding witness points by the plant or its designated representative.

5. Any variation from the original schedule that is due to a non-conformance shall be brought to the immediate attention of the plant contact. Any non-conformance that materially impacts the performance, reliability, or maintainability of the unit or the form, fit, or function of the parts shall not be corrected without plant input and agreement. During plant meetings to discuss LP rotor and component part manufacturing status, the status of the installation will also be addressed and a status update provided.

6. A detailed installation plan shall be provided by the supplier no later than six months prior to the start of the outage, and within that plan shall be a pre-outage plan and schedule that cover all issues and other preparatory work necessary to be ready to start LP turbine replacement rotor work activities at the desired start date. This plan should cover all contract personnel obtaining sufficient training to perform the work to be done while meeting all safety, environmental, and regulatory requirements at the plant site.

7. Meetings will be held at the plant site to review progress of manufacture and delivery, based on need and mutual agreement. During such meetings, the schedule of manufacture for all major items shall be discussed and the existing status reported, including the days ahead/behind of schedule and the basis why. Major items are considered to be the rotor forging, rotating buckets/blades, stationary components, or other items deemed important by the plant such as monitoring hardware and software.

8. Visits by plant or third-party representatives to supplier's facilities shall be conducted based on need and mutual agreement to witness milestones or other important activities being

accomplished during the manufacture of the components. During such visits, the plant representatives will be obtaining information identified within this request and required within the contract or purchase order.

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accomplished during the manufacture of the components. During such visits, the plant representatives will be obtaining information identified within this request and required within the contract or purchase order.

1.5 EVALUATION AND SELECTION OF SUPPLIER

Responses will be reviewed by the following organizations and a manufacturer selected based on their responses:

- Organization 1:
- Organization 2:

Issuance of a purchase order or contract will be contingent upon review of supplier's information, guarantees, warranties, and liquidated damages in accordance with those identified in this procurement package. Response by the supplier to this request for quotation (RFQ) indicates an agreement to cooperate and participate in the technical review process. Prior to involvement of any third-party consultant, appropriate arrangements will be made to protect any proprietary information. Information supplied in response to this request shall remain confidential and shall be returned to the supplier if not awarded a purchase order or contract. After completion of the selection process, the attached specification shall be finalized and attached to a letter of intent to purchase placed with the selected supplier. Issue of a final purchase order shall be contingent upon final review and agreement of terms, conditions, and technical criteria governing the purchase of the rotors.

1.6 RESPONSE FORMAT

Forms are attached that suppliers are expected to complete. These forms conform to and summarize the details of the procurement request and should be included with the bid package. Exceptions to either the commercial or technical requirements identified in this RFQ and itemized in these attachments should be stated in the space provided within each respective attachment.

1.	Cost Breakdown	Attachment 1
2.	Warranties and Penalties	Attachment 2
3.	Milestones for Manufacture and Delivery	Attachment 3
4.	General Criteria and Codes/Standards	Attachment 4
5.	Checklist of Technical Criteria – Rotor Forging	Attachment 5
6.	Checklist of Technical Criteria – Rotating Blades	Attachment 6
7.	Checklist of Technical Criteria – Stationary Components	Attachment 7
8.	Shipping, Coordination, and Support	Attachment 8
9.	Inspection, Alignment, and Balancing	Attachment 9
10.	Performance Improvements	Attachment 10

1.7 SCHEDULE FOR REVIEW AND AWARD OF CONTRACT

The objective for the plant is to install the replacement low-pressure rotors during a scheduled outage between the weeks of June 1 to July 21in 2006. Pursuant to this objective, the bidder's response shall be reviewed as follows unless otherwise notified:

Date	Selection Process Milestone
3/01/01	1. Issue RFQ
4/01/01	2. Deadline for response to RFQ
5/01/01	3. Selection of potential manufacturer
5/05/01	4. Letter of Intent to manufacturer
5/31/01	5. Completion of technical review
6/01/01	6. Negotiation and issue PO or contract

The plant commercial contact and the plant technical contact for the RFQ are as noted below:

Commercial Contact	Technical Contact
Name: ________________	Name: ________________
Phone: ________________	Phone: ________________
Fax: ________________	Fax: ________________
E-mail: ________________	E-mail: ________________

2. BACKGROUND/GENERAL DESCRIPTION OF UNIT

2.1 GENERAL DESCRIPTION OF UNIT

The [XXXXXX Unit X] turbine-generator operates with a live steam of [1250 psi/953°F] is rated at [500 MW] and was manufactured by [XXXXXXXXXX Electric Company]. The unit was commissioned in [19XX]. The existing turbine at the station has a [14-stage single-flow HP/IP] turbine that is coupled to [two double-flow 12-stage LP] turbines having a [36"] last stage blade. The LP turbine is coupled to a [four-pole] generator turning at [3600 rpm] with a rating of [500,000 kW at 90 percent power factor]. The journal sizes for the LP turbines are [xx] inches with coupling diameters of [xx] inches each having [xx] inch diameter bolts respectively. Low-pressure turbine rigging drawings are attached that show centerline distance between bearings and other pertinent dimensional data, such as jackshaft sizes. In addition, a rotor clearance drawing is also attached for the specific low-pressure rotors to be replaced. The low-pressure rotor bearings are [tilt pad] with [x.xx] mils per inch diametrical clearance at each bearing. A cross-sectional drawing of the turbine is also attached for a more descriptive pictorial view of the turbine unit.

2.2 ROTOR CONFIGURATION

The low-pressure rotor to be replaced has [shrunk on discs] and is made of [ASTM A470 class 6] material. The turbine consists of [12 total stages, six] per opposing end to form a double-flow configuration. The stages are identified as the [L-0 to L-5] from the exhaust of the turbine to the inlet, respectively. The rotor disks are keyed to the shaft. There is [one wheel per rotating stage of blades] in each flow direction. [The rotors are direct coupled to each other with bolted couplings.] The blades are attached to the disks around the outer edges to form a rigid assembly. The buckets are manufactured of [12% chrome-alloy] steel and range in length from [4" on the L-5 stage to 36" on the L-0 stage]. A fixed sealing strip between the blade covers and the outer perimeter of the inter-stage diaphragm for each stage prevents steam leakage over the outer edge of the moving buckets. [The last stage (L-0) has no cover at the tip of the blades.]

[Interstage diaphragms are attached to the turbine casing and contain the partitions (fixed nozzles) that redirect the steam through each stage of moving buckets. These diaphragms are split horizontally and have spring-backed packing rings where they seal with the shaft. Both halves of the diaphragms are keyed to their respective turbine casing halves and have a machined fit along their horizontal surface.]

2.3 TURBINE RATING AND STEAM CONDITIONS

1. Unit output (kilowatts)
2. Fuel type (coal, oil, natural gas, other)
3. Type unit operation (base load, start-stop, load following)
4. Steam flow
5. Main steam pressure
6. Main steam temperature
7. Reheat steam pressure
8. Reheat steam temperature
9. Exhaust pressure
10. Gross turbine cycle heat rate
11. Type boiler and manufacturer
12. Boiler rating (steam flow, pressure, temperature)
13. Cycle chemistry: (A) type treatment
    (B) boiler water
    (C) feedwater
    (D) steam

A heat balance diagram of the unit is attached.

2.4 HISTORIC CONCERNS

GE TIL concerns

EPRI paper

[The existing low-pressure turbine rotor has a history of developing stress corrosion cracks in both the disk keyways and in the disk attachment regions of the L-0 rows. There have also been fatigue failures in the L-0 rows, with cracks originating in the trailing edges of the airfoils where flame hardening was applied for erosion protection.]

3. GENERAL STATEMENT OF COMPATIBILITY

The replacement low-pressure rotors provided under this procurement contract shall:

1. Be completely compatible with the existing [LP] turbine steam path components, bearings, couplings, and glands/packing cases

2. Result in no significant operational changes after replacement, when compared against unit operation with the current [LP] rotor

3. Have no negative impact on existing feedwater heaters used in the [LP] turbine sections

4. Result in no abnormal or high rotating/stationary blade steady or dynamic stresses at extraction locations

5. Place no limitation on the operation, maintenance, safety, or environmental requirements of the plant

It is recognized that either new stationary row designs or modifications to the overall [LP] section may be required to improve performance and output, increase unit reliability and availability, or result in a significant reduction of outage maintenance overhaul time. As long as such factors do not affect items 2 and 3, preference for complete compatibility can be modified, depending upon the technical advantages, justifications, and guarantees offered by the supplier quoting a replacement rotor.

4. CODES AND STANDARDS

1. The latest issue of all codes and standards referenced in this specification shall apply when the purchase order or contract is released. Specific codes and standards that are applicable under this request for proposal are listed as follows:

ASTM A275/ A275M-98	Standard Test Method for Magnetic Particle Examination of Steel Forgings
ASTM A276-00a	Standard Specification for Stainless Steel Bars and Shapes
ASTM A314-97	Standard Specification for Stainless Steel Billets and Bars for Forging
ASTM A370-97a	Standard Test Methods and Definitions for Mechanical Testing of Steel Products
ASTM A418-99	Standard Test Method for Ultrasonic Examination of Turbine and Generator Steel Forgings
ASTM A470-01	Standard Specification for Vacuum-Treated Carbon and Alloy Steel Forgings for Turbine Rotors and Shafts
ASTM A472-98	Standard Test Method for Heat Stability of Steam Turbine Rotor Shafts and Rotor Forgings
ASTM A473-01	Standard Specification for Stainless Steel Forgings
ASTM A484/484M-00	Standard Specification for General Requirements for Stainless Steel Bars, Billets, and Forgings
ASTM A582/A582M-95b (2000)	Standard Specification for Free-Machining Stainless Steel Bars
ASTM A751-96	Standard Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products
ASTM A768-95	Standard Specification for Vacuum-Treated 12% Chromium Allow Steel Forging for Turbine Rotors and Shafts
ASTM E353-93(200)e1	Standard Test Method for Chemical Analysis of Stainless, Heat Resisting, Maraging, and Other Similar Chromium-Nickel-Iron Alloys
ASTM E381-01	Standard Method of Microetch Testing Steel Bars, Billets, Blooms and Forgings

2. Materials being supplied by any manufacturer with this bid shall meet all local, state, or federal standards required by various government agencies within the United States.

3. It is the supplier's responsibility to provide for sufficient QA/QC measures to ensure that parts manufactured by its vendors, vendor-suppliers, or subsuppliers meet these requirements.

4. Correction for non-compliance with the above standards in existence at the time the items were purchased shall be corrected by the rotor supplier and at a time convenient to the plant.

5. These requirements shall remain in effect for 10 years after receipt by the plant.

5. TECHNICAL CRITERIA – ROTOR FORGING

5.1 MATERIALS, DESIGN, AND LOADS

1. The manufacturer of the rotor and/or supplier of the forging shall be identified in the bid. The forging material and mechanical properties shall be in accordance with ASTM A370 Class 6 standards unless otherwise stated.

2. Prior to acceptance of the forging, specimens will be taken and tested by the manufacturer of the forging to establish the suitability of its chemical and material properties Chemical properties of the forging shall conform to the limits in Table B-1 and be optimized to achieve a "superclean" steel forging. Exceptions to the material and mechanical criteria shown in the table shall be identified by the rotor manufacturer and addressed by the supplier in Attachment 5 of their bid.

Table A-1
Material and Mechanical Criteria for the Forging

Mechanical Properties		Chemical Concentration	
Yield strength (ksi)	620 minimum	Carbon	0.28–30
Tensile strength (ksi)	725–860 minimum	Silicon	0.05–0.10
Elongation (%)	17-18	Magnesium	0.20–0.40
Reduction in area (%)	52-50	Phosphorous	0.12 max
Charpy Impact (ft-lbs)	61.2	Sulfur	0.15 max
FATT (ΔF)	50 (20°F)	Nickel	3.25–4.00
		Chromium	1.25–2.00
		Molybdenum	0.25–0.60
		Vanadium	0.05-0.15
		(Trace elements: Al, Sn, As, Sb)	0.002–0.005

3. Prior to any testing, a legible sketch or drawing shall be supplied for review that indicates the exact dimensional location and size of the test specimen used, and the direction from which specimens are to be taken.

4. Prior to acceptance of the forging from the manufacturer, the supplier shall provide for review the results of the chemical and mechanical property tests obtained from the forging, showing compliance with the appropriate ASTM standards and requirements of this specification.

5. Nominal allowable wheel dovetail or steeple stresses in all blade/bucket rows and maximum concentrated stresses in the wheel dovetail or steeples for each row will be identified and supplied with the bid.

6. Upon receipt of a letter of intent to purchase, a one-fifth scale drawing of the rotor with rim design loads identified will be provided for technical review of the design.

7. Upon receipt of a letter of intent to purchase, results of finite element stress calculations for all wheel dovetails or steeples of each row will be provided for review where such analyses have been performed.

5.3 NDT AND QC CRITERIA

1. The supplier and/or rotor manufacturer shall guarantee the absence of cluster indications greater than 0.0625" throughout locations of the forging body except those areas to be machined.

2. In their bid, the supplier shall describe all NDE equipment (transducers, etc.) and calibration procedures to be used, identify the various tests to be performed, and state the rejection criteria to be applied for each test that is conducted.

3. Ultrasonic testing is to be performed to supplier's and/or manufacturer's stated requirements, which shall, as a minimum, be in accordance with ASTM A418-99. Before assembly of the rotor, copies of all test results are to be provided for review.

4. Magnetic particle examination of the rotor is to be performed to supplier and/or manufacturer's stated requirements, which shall, as a minimum, be in accordance with ASTM A275/A275M-98. Before assembly of the rotor, copies of all test results are to be provided for review.

5. If tests indicate that a bore is required, the supplier shall not bore the forging without approval. The purchaser will not be held accountable for shipping delays associated with obtaining this approval.

6. For rotor forgings that must have a bore, the new rotor shall contain no cluster indications greater than 0.25" when examined with a detection system capable of finding a 0.050" flaw or larger 50% of the time and a 0.070" flaw 90% of the time within 4" of the bore surface. Prior to installation of the buckets, results of the post-boring ultrasonic test will be provided for review.

5.5 SCHEDULE FOR REQUIRED DOCUMENTATION

Unless otherwise indicated in their response, the supplier will provide the required documentation associated with rotor forging in accordance with the schedule shown in Table B-2.

Table A-2
Rotor Forging Documentation

Reference	Documentation	Supplied with Bid	Upon Award	Prior to Assembly	Prior to Shipping	Prior to Startup
5.1.1	Forging manufacturer identification	X				
5.1.3	Location of forging test sample locations	X				
5.1.5	Results of all mechanical and chemical property tests			X		
5.1.6	A 1/5 scale drawing of the rotor with rim loads		X			
5.1.8	FE results of wheel/steeple stresses		X			
5.2.1	Recommendation to bore, documented by UT results			X		
5.2.3	Copy of the complete heat treat record			X		
5.2.4	Results of heat stability test of the forging			X		
5.2.6	Recommendations of coatings or shot peening	X				
5.2.7	Results of coatings or shot peening (if performed)			X		
5.3.2	NDE tests, equipment, procedures, rejection criteria	X				
5.3.3	Copy of ultrasonic test results from the forging			X		
5.3.4	Copy of magnetic particle test results for the forging			X		
5.3.6	If rotor is bored, UT results after bore is finished			X		
5.4.3	Copy of action taken on all approved NCR items				X	

6. TECHNICAL CRITERIA - ROTATING BUCKETS/BLADES

6.1 MATERIALS, DESIGN, AND LOADS

1. Information identifying the basic blade designs and configuration for each rotating row of the turbine shall be identified and provided with the bid using Table B-3. Acceptable materials are as shown in Table B-3 unless otherwise specified by the supplier.

Table A-3
Acceptable Material for Rotating Buckets/Blades

Part	Acceptable Material
Blade	AISI 630 (17-4PH), AISI 410, AISI 403, Jethete M-152
Covers	AISI 630 (17-4PH), AISI 410, AISI 403
Pins	AISI H11, ASTM A193GRB16
Tie Wires	AISI 630 (17-4PH), AISI 316
Cross-Keys	Type M252 austenitic steel rod
Notch/Bucket	Ti-6Al-4V or equivalent

2. The name and address of the stock material supplier and/or blade manufacturers (if other than the supplier) shall be provided with the bid.

3. The material and mechanical properties of the blades will be in accordance with the appropriate ASTM codes and standards referenced in Section 4 of this RFQ.

4. For blades with an airfoil length less than or equal to 8" long, all cross-sectional centers (R, ¼, ½, ¾, T) of gravity in the axial and tangential directions shall fall within a 0.062" (1.58 mm) radius described about the dovetail center of gravity. Exceptions to any of these design factors will be supplied with the bid.

5. For blades with an airfoil length greater than 8" long, all cross-sectional centers (R, ¼, ½, ¾, T) of gravity in the axial direction shall fall within a 0.186" (4.72-mm) radius described about the dovetail center of gravity. In the tangential direction, the bucket cross-sectional centers (R, ¼, ½, ¾, T) of gravity shall fall within a 0.062" radius. Exceptions to any of these design factors will be supplied with the bid.

6. Allowable nominal running speed design factors of safety in all rotating blade rows shall not exceed those shown in Table B-4. Exceptions to any of these design factors will be supplied with the bid.

Table A-4
Allowable Nominal Running Speed Safety Factors

Stress Location	Description	Safety Factor
Blade	Tension in vane root	2.5
	Tension in bucket neck	2.5
	Average shear on bucket hooks	2.5
Wheel	Tension in wheel neck (plus rim stresses)	2.5
	Average crushing stresses in wheel hood	2.5
	Average shear stress on wheel neck	2.5
	Average shear on wheel hooks	2.5
Notch Closure Piece	Shear in pins and cross-keys	3.0
	Tension in bucket at centerline of cross-keys	2.0
	Average shear on bucket hooks adjacent to notch	1.8
	Shear in notch closure piece below lower pin	1.8
	Shear below cross-key in notch closure piece	1.8
	Shear above upper cross-key in adjacent bucket	1.8
	Shear in wheel hooks adjacent to notch	2.0
	Tension in bucket at centerline of upper pin	2.0
	Shear on wheel neck adjacent to notch	2.0
	Shear in bucket neck adjacent to notch	1.8
	Concentrated tangential stress at the notch wheel rim	2.0
Cover and Tenons	Tenon shear - marginal stages	6.0
	Tenon shear - all others	3.0
	Cover side bending stress	2.5
	Cover bend stress over notch	1.25
	Cover single span bending stress	1.25
	Cover corner bending stress	2.5
	Cover end bending stress	2.5

7. To obtain approved exceptions for any of these design factors, results of finite stress calculations shall be provided upon receipt by the supplier of a letter of intent to purchase from the purchaser.

8. The supplier will design any rotating blades that exceed 12" in length so that a minimum of 10-hertz margin from a per-rev forcing is achieved for each of the first four resonant modes while at speed.

9. Prior to assembly of the rotor, Campbell and/or interference diagrams based on test results obtained from calculation, spin pit, or field telemetry testing shall be provided for all rows >12" (304.8 mm) to show adequate tuning from resonance.

10. The L-0 stage should be designed so that the unit can operate up to 10 inches Hg back pressure without flutter occurring.

11. If freestanding blades are used in the L-0 rotating rows, the blades will be further designed to be mix-tuned to prevent or resist flutter when at speed and under load.

6.2 MANUFACTURING AND PROCESSING CRITERIA

1. Prior to assembly, the rotor supplier shall provide for review copies of material test certificates after the material has been modified to meet the supplier's criteria.

2. The use of flame-hardened leading edges is not allowed due to numerous problems in maintaining and ensuring quality control during the application.

3. The supplier will identify whether coatings and/or shot peening will be used on any areas of the bucket or whether brush seals are to be used and for which rows.

6.3 NDT AND QC CRITERIA

1. All rotating blades shall be free of any visible signs of deterioration that might be classified as cracks, dents, missing metal, or corrosion.

2. Prior to assembly, the supplier shall provide copies of the blade NDE tests and acceptance criteria that are applied to each row and the results of the tests for review. This shall apply to any dye penetrate, X-ray, zyglo, magnetic particle, eddy current, or ultrasonic testing.

3. Prior to assembly, the supplier shall provide review copies of the certificates if shot peening is performed on any rotating rows.

4. Prior to the blades' assembly on the rotor, the supplier shall perform moment weighing of each row and provide copies of the moment weight and assembly charts for each blade row.

5. Prior to their assembly on the rotor, any blades designed to have fundamental modes of vibration operate within specified frequency ranges will be individually tested to check and compare the consistency (quality control) of their dynamic characteristics. All devices used to obtain frequencies are required to have sufficient range to identify and document the frequencies of the first two modes and to perform measurements within an accuracy of 1.0 hertz. Results of these tests will be provided for each blade and row that is tested.

6. Before the blades are assembled on the rotor, results from *in situ* telemetry or spin-pit tests will also be provided for any (1) newly designed blades (that is, with minimal or no operating experience), (2) any titanium blade rows, or (3) any rows with titanium notch blade groups. Copies of test results shall be provided in the form of Campbell or interference diagrams to demonstrate that the resulting frequencies achieve design expectations.

6.4 NON-CONFORMANCE

1. After installation, checks will be performed to ensure that any blades, pins, covers, tie wires, and tenons are properly sized to ensure that proper contact and correct mating occurs between all surfaces designed to be in contact during operation, for example, roots, adjacent platforms, and linkages between adjacent airfoils.

2. Blades within a specific row on one end of the turbine shall be totally interchangeable with the same end on a second turbine of the same design that is purchased through this RFQ.

3. Blades that exceed the standards or criteria established in the contract will be scrapped and replaced at no cost to the purchaser.

4. Any NCR action taken that changes the original design dimensions, fit, or function of the blades used in any row of the turbine shall be reported prior to undertaking any corrective action. The purchaser reserves the right to approve or disapprove any change that may impact the intent of these criteria.

5. The supplier shall maintain a detailed record of all non-conformance issues and shall provide a copy of this information when the assembled rotor is shipped to the plant.

6.5 SCHEDULE FOR REQUIRED DOCUMENTATION

Unless otherwise indicated in their response, the supplier will provide the required documentation associated with the turbine blades in accordance with the schedule as shown in Table B-5.

Example of a Turbine Bucket RFQ

Table A-5
Rotor Blades Documentation

Reference	Documentation	Supplied with Bid	Upon Award	Prior to Assembly	Prior to Shipping	Prior to Startup
6.1.1	Listing of basic design features for each row	X				
6.1.2	Name/address of material and blade suppliers	X				
6.1.7	FE results to support exceptions to factors of safety		X			
6.1.9	Frequency margins for blades >12" (304.8 mm) in length			X		
6.2.1	Test certifications of materials			X		
6.2.2	Recommended shot-peening, coating, brush seals	X				
6.3.2	NDE acceptance criteria and results			X		
6.3.3	Shot-peening certificates for each row			X		
6.3.4	Moment weights and assembly charts for each row			X		
6.3.5	Frequency test results for all tuned rows			X		
6.3.6	Telemetry or spin pit test results for new rows			X		
6.4.1	Inspection, QA/QC checks performed during assembly					X
6.4.5	Detailed record of all non-conformance issues			X		

7. TECHNICAL CRITERIA – STATIONARY COMPONENTS

7.1 MATERIALS, DESIGN, AND LOADS

1. Any stationary components to be provided or required as part of the LP rotor replacement will be identified and listed by part numbers in the bid and shall meet the requirements presented in this section of the procurement specification as a minimum.

2. Any new stationary blading that is being supplied along with the new rotors shall be designed to offer improved performance and/or reliability over the original stationary blades.

3. Materials used in the construction of stationary parts shall be prepared in conformance to ASTM standards. Materials used by the supplier to produce the stationary airfoils shall be identified in the bid. Bar stock material used for production of airfoils shall conform to ASTM A276 and prepared in accordance with the analysis requirements of ASTM A751-96 and ASTM E353.

4. If the supplier elects to offer alternative materials that have superior or advantageous properties or performance, these are to be identified as part of their bid. However, the same level of information as noted in the above ASTM standard will be required. The extent of any price increase should be clearly identified in the cost section of the bid.

5. Prior to assembly, copies of certificates of bar stock material properties used to produce airfoils shall be provided for review.

6. Materials used in stationary airfoils shall be selected to maximize resistance to moisture and water erosion.

7. The stationary airfoils shall be aerodynamically designed to maximize performance and reliability and to collect and drain as large a volume of water/water droplets as possible that may collect on the vanes and nozzle sidewalls.

8. The supplier will identify within the bid the planned use of any coatings, inserts, or weld buildup to minimize the erosive affects of moisture in certain areas of the stationary rows.

9. Strategies to optimize either the exhaust flow guide or the exhaust hood internals as a way to minimize leaving losses should be presented in the bid.

10. Strategies to minimize leakage by the shaft with the use of brush seals should be presented in the bid.

7.2 MANUFACTURING AND PROCESSING CRITERIA

1. The preferred method of manufacture of stationary rows is by fabrication with the outer rings, vanes, and inner webs produced from material that resists surface loss due to water impingement,

washing, and erosion. Alternative methods of construction will be considered and should be presented in the bid.

2. Bars used to produce stationary vanes shall be cut into lengths and be dimensioned such that removing surface material may produce the final shape of the guide vanes. The bar stock shall be hot formed with sufficient excess material so that any piping seams, cracks, flaws, fins, hard spots, or undue segregation can be removed by machining.

3. The heat treatment process of the vane sections is to be in accordance with the manufacturer's specification and reviewed and approved by the purchaser prior to their fabrication. Furnace records are to be taken using calibrated instrumentation for all heat treat processes.

4. Prior to fabrication of the stationary parts, copies of the heat treatment charts that trace their thermal history are to be supplied for review for each bar.

5. A vane profile-stacking diagram is to be provided before final assembly with sufficient details at each section at suitable radial heights so that a profile template can be produced and used to check every vane before they are assembled into the inner and outer rings.

6. After final fabrication, stationary nozzle halves are to be stress relieved, if required, to remove any residual stresses produced by the fabrication process. During the stress-relief cycle, the vanes, inner sidewalls, and outer sidewalls are to be coated with material that prevents damage by oxidation, reduction, or harmful effects that would cause their condition to deteriorate while in service.

7. The final assembly of the outer ring, vanes, and inner web shall be performed in a manner sufficient to produce a rigid assembly that is capable of locating the fixed blade elements in the correct axial, tangential, and radial location under all situations of transient steam conditions and further provide a steam seal barrier to minimize steam leakage bypassing the fixed vanes.

8. After final assembly and machining of the inner and outer rings, the vane discharge portion shall be adjusted to meet the stated requirements without imparting a high per rev stimulus to the rotating blade row.

9. A harmonic stimulus analysis shall be performed for each stage greater than 13" in radial height. Results are to be provided to the plant before shipment of the parts. Necessary corrections shall be made to minimize the effect of high per rev stimuli from the stationary nozzles prior to their shipment to the plant.

10. The stationary blade/nozzle assembly shall be designed in such a manner so that alignment of the component to the rotor can be accomplished by shimming the part vertically and horizontally to achieve the desired results. Spare shims shall be provided for each stationary element for use during future overhauls to speed the alignment process.

7.3 NDT AND QC CRITERIA

1. All stationary components shall be free of any visible deterioration that might be classified as cracks, dents, missing metal, or corrosion.

2. The surface finish of the stationary airfoil or vanes shall have a 32 RMS finish on both the concave and convex sides.

3. The exhaust edge shall (a) be radial within 5 mils per inch with 60 mils maximum deviation from end to end, (b) be straight within 10 mils per inch, maximum 30 mils in 12 inches and 60 mils total as checked by a feeler gage under a straight edge, and (c) have the blending radius to the sidewall of 1/16" ±1/32".

4. Total area shall be within ±2% of design. Prior to shipment, the supplier shall provide a copy of pitch and throat measurements performed by them or their supplier that shows the calculated area for each stage. The design area shall be included with this information.

5. Radial height measurements shall be made by the manufacturer and shall be within ±0.060" of design. Results of these checks on all stages shall be provided for review prior to the shipment of the parts.

6. Individual area of each throat shall not exceed ± 2% of design. Individual area calculations shall be provided by the supplier showing comparison to design area, prior to shipment of the parts.

7. Individual throat measurements of X (1" from the outer sidewall), Y (at the pitch line), and Z (1" from the inner sidewall) shall be within ±3% of design. This data obtained from each stage shall also be provided for review prior to shipment of the parts. Throat readings may vary in distance from the sidewalls as a function of radial height of the nozzle; therefore, this should be accounted for when making such measurements. Pitch readings at X, Y, and Z shall be within ±2% of design. Results of these checks shall be provided for all stages prior to the shipment of the parts.

8. Stationary bores shall be concentric within 2 mils, round within 5 mils, and parallel to sealing faces that seal to the inner casing tongue fits within 3 mils. Diameter measurements and dial indicator readings shall be recorded and copies submitted for review. Horizontal joints shall have 95% joint contact in the unbolted position.

9. All bolting used on stationary components shall be standard 8 threads per inch; no metric threads will be allowed.

7.4 NON-CONFORMANCE

1. After installation, checks will be performed to ensure that all stationary components supplied under this bid are properly sized to ensure their aerodynamic performance as designed by the

manufacturer and in conformance with the conditions of this specification. Any parts that exceed the standards or criteria of the contract shall be scrapped and replaced at no cost to the purchaser.

2. Any NCR action taken that changes the original design dimensions; fit, or function of the stationary parts used in any stage of the turbine shall be reported to the plant prior to taking any corrective action. The plant reserves the right to approve or disapprove any change that may impact the intent of these criteria.

3. The manufacturer shall maintain a detailed record of all non-conformance issues and shall provide this information when the assembled rotor is shipped to the plant.

7.5 SCHEDULE FOR REQUIRED DOCUMENTATION

Unless otherwise indicated in their response, the supplier will provide the required documentation associated with the stationary components in accordance with the schedule as shown in Table B-6.

Table A-6
Stationary Components Documentation

Reference	Documentation	Supplied with Bid	Upon Award	Prior to Fabrication	Prior to Shipping	Prior to Startup
7.1.1	Listing of original stationary parts to be replaced	X				
7.1.3	List of materials used to produce vanes	X				
7.1.4	List of recommended alternative materials	X				
7.1.5	Certificate of vane material properties		X			
7.1.8	Identification of coatings, inserts, or weld build-up	X				
7.1.9	Strategies to minimize leaving losses	X				
7.1.10	Strategies to minimize leakage	X				
7.2.1	Description of methods other than fabrication	X				
7.2.3	Heat treatment standards to be applied		X			
7.2.4	Heat treatment charts for each bar			X		
7.2.5	Vane stacking diagram for each row		X			
7.2.9	Results of harmonic stimulus analysis (>13")			X		
7.3.4	Pitch and throat measurements for each row			X		
7.3.5	Individual area checks compared to design area			X		
7.3.6	Results of radial height measurements for each row			X		
7.3.7	Results of individual throat/sidewall measurements			X		
7.4.1	Detailed record of any non-conformance issues			X		

8. SHIPPING, COORDINATION, AND SITE SUPPORT

8.1 SHIPPING

1. The supplier will be responsible for selecting a carrier and making arrangements for the shipping of parts. Shipping costs will be in accordance with the contracted price.

2. The supplier will be responsible for replacing any parts lost, stolen, or damaged during the course of shipping parts to the plant.

3. Prior to shipping, a part number listing and other information required to order the supplied parts shall be provided for the rotor, individual buckets, and all components involved with the replacement assembly.

4. Prior to shipping, a list of units, contact names, and telephone numbers shall also be provided where such parts are interchangeable.

8.2 COORDINATION, DRAWINGS, AND TOOLS

1. All drawings necessary for installation of the rotor and its stationary components into the existing units to shall be provided prior to shipment of the order. This will include; (a) instruction book longitudinal drawings of the replacement LP rotor along with LP rotor radial and axial clearances; (b) maintenance and rigging drawings necessary to perform future maintenance of the unit; (c) specific drawings to support any design changes made or that may be needed in the future; and (d) LP rotor drawing showing balance weight radii, location from rotor's center of gravity, and specifying balance weight dimensions and weight.

2. A list of tools, equipment, personnel, and technical support required by the supplier to disassemble/reassemble unit, remove old parts, prepare the turbine for the new rotor, install the new rotor, slow-speed/high-speed balance the rotor, and perform performance testing of the unit will be provided prior to shipment of the order.

3. A listing of plant support requirements will be provided, prior to shipment of the order. This is to include machining detail drawings required to perform field-machining activities at the plant site and which the plant may do.

4. A checklist or sign-off sheet of inspections and tests to be conducted during the rotor removal, section inspection and cleaning, unit assembly, and slow-speed/high-speed balance of the new rotor shall be provided no later than two weeks prior to when work is to begin on-site.

5. Upon arrival on-site, each checklist will be reviewed to verify specific support required of the plant personnel identified by the supplier to complete the activity in accordance with the supplier's schedule.

6. Prior to leaving the site, the supplier will provide system description information and drawings that may be required as part of plant requirements or to modify existing plant maintenance or operating procedures.

7. Prior to leaving the site, the supplier will provide safety and environmental instructions or manuals that may be required for future operations and maintenance of the unit. This will assist the utility with performing future work according to the rules set forth by regulatory agencies.

8.3 SCHEDULE FOR REQUIRED DOCUMENTATION

Unless otherwise indicated in their response, the supplier will provide the required documentation associated with shipping and site coordination in accordance with the schedule as shown in Table B-7.

Table A-7
Shipping and Site Coordination Documentation

Reference	Documentation	Supplied with Bid	Prior to Assembly	Prior to Shipping	Prior to Startup	At contract conclusion
8.1.3	Parts number listing as required to order parts			X		
8.1.4	List of units, contacts with interchangeable parts			X		
8.2.1	Drawings necessary to support field installation and future maintenance.			X		
8.2.2	List of tools, equipment, and personnel to support disassembly, installation, and reassembly			X		
8.2.3	List of plant support required during disassembly, installation, and reassembly			X		
8.2.4	Checklist/sign-off sheets of inspections and tests performed during disassembly and reassembly			X		
8.2.6	System description information and drawings that may be required as part of plant requirements or to modify existing procedures					X
8.2.6	Safety and environmental instructions or manuals that may be required for future operations and maintenance of the unit according to the rules set forth by regulatory agencies					X

9. INSPECTIONS, ALIGNMENT, AND BALANCING

9.1 INSPECTION CRITERIA

1. Prior to removal of the original parts, notable signs of damage or wear to the section will be identified, recorded by the supplier, and reviewed with the plant manager.

2. Upon removal of the original parts, those to be re-used with the new rotor taken from the turbine section will be cleaned and inspected for any signs of noticeable fatigue, damage, or wear. Results of the inspection will be recorded and verified with recommendations for corrective action, if any, to be immediately provided.

9.2 ALIGNMENT CRITERIA

1. The supplier shall provide with the bid the extent of the cantenary and coupling alignment changes that are expected to occur and how re-alignment will be performed during installation in order to minimize outage time.

2. Alignment corrections shall be reflected in the instruction book and via drawings that are to be provided by the supplier prior to shipping the rotor.

3. The supplier shall perform alignment corrections at no cost to the plant.

9.3 SHAFT-SYSTEM TORSIONAL RESONANCE RESPONSE CRITERIA

1. The new LP rotors shall be designed in a manner such that the turbine-generator shaft system cannot respond to torsional excitation that may occur at a forcing frequency of 60 or 120 hertz under either steady state or transient conditions.

2. The supplier shall ensure that the coupled rotor torsional resonance frequencies of the unit will have a minimum measurable frequency margin of ±2 hertz from a 60 or 120 hertz forcing frequency.

3. The supplier shall be responsible for parts and/or any necessary modifications to existing and new components and any necessary testing before/after the new LP rotor installation in order to ensure that these criteria are met.

4. If testing is to be performed, the supplier shall provide with the bid a detailed plan as to how such tests will be performed and the length of time such tests will take. The plant reserves the right to refuse any portion of such tests if they could impact unit operation or result in damage to turbine equipment. A copy of the results of any torsional response tests will be provided.

5. If no testing is planned and the torsional response assessment is based on calculations alone, the minimum acceptable frequency margin shall be ±4 hertz from a 60 or 120 hertz forcing frequency. Results of these calculations will be provided at least one month in advance of rotor shipment.

[redacted]

Low Speed Balance

9.4 ~~HIGH-SPEED SPIN P~~IT AND FIELD BALANCING CRITERIA

1. High-speed spin pit balancing of the low-pressure rotor shall be performed at critical speed, running speed, and overspeed, if necessary. Problems or concerns regarding this requirement shall be stated in the bid.

2. An LP rotor shall be considered balanced when vertical and horizontal absolute shaft and coupling vibration meet the criteria shown in Table B-8.

Table A-8
Vibration Criteria

For Rotors That Operate Between the First and Second Critical Speeds		
Location	**1800 rpm**	**3600 rpm**
Shaft	1.5 mils peak-peak	1.0 mils peak-peak
Coupling	2.5 mils peak-peak	2.0 mils peak-peak
For Rotors with Critical Speeds Greater Than 300 rpm from Running Speed:		
Location	**1800 rpm**	**3600 rpm**
Shaft	3.0 mils peak-peak	2.0 mils peak-peak
Coupling	5.0 mils peak-peak	4.0 mils peak-peak
For Rotors with a Critical Speed from 100 to 300 rpm of Running Speed:		
Location	**1800 rpm**	**3600 rpm**
Shaft	2.0 mils peak-peak	2.0 mils peak-peak
Coupling	4.0 mils peak-peak	3.0 mils peak-peak
For Rotors with a Critical Speed Less Than 100 rpm of Running Speed:		
Location	**1800 rpm**	**3600 rpm**
Shaft	1.5 mils peak-peak	1.0 mils peak-peak
Coupling	2.3 mils peak-peak	2.0 mils peak-peak

3. The rotor shall be maintained at operating speed for a minimum of 30 minutes with no more than a 0.5 mil vector change occurring. For an LP rotor that operates between the first and second critical speed in the field, the absolute shaft and coupling vibration taken at the unit operating speed of 1800 rpm or 3600 rpm shall not exceed the levels shown (after correcting for slow roll run-out).

4. LP rotors designed to operate above their second critical speed in the spin pit and/or in the field shall meet the stated criteria, and in addition, the absolute static unbalance at speed shall be less than 0.7 mils (0.018 mm) in order to minimize the third mode effects at operating speed.

5. Absolute shaft and coupling vibration taken during roll-up and roll-down through critical speeds shall not exceed the criteria shown, after correction for slow roll run-out.

6. Results of the high-speed balance of the rotor are to be provided before installation. A designated plant representative shall not accept changes beyond the vibration values shown without a thorough explanation by the supplier. These changes are subject to final approval by the utility.

[redacted]

9.5 ON-SITE SHAFT-SYSTEM BALANCE AND VIBRATION CRITERIA

1. The new LP rotor shall be designed in a manner such that the ounce-inch balance capability of the new rotor is equivalent to that of the old rotor when accounting for both field and factory balance planes.

2. Installation of the new LP rotor into the shaft train shall not result in any detrimental impact on the absolute vibration (mils (mm) peak to peak after correcting for slow roll run-out) of other rotors at critical speed or running speed in either the vertical or horizontal directions.

3. The maximum slow roll run-out (mechanical and electrical) of the new LP rotor shall not exceed 1 mil.

4. The shaft train vibration after installation of the new LP rotor shall be less than before the LP rotor was replaced. Potential sellers are encouraged to obtain vibration on the unit prior to rotor installation in order to ensure that this criterion can be achieved.

5. Minimum acceptance criteria for unit absolute vibration in mils peak to peak after correcting for run-out shall be as shown in Table B-9. The manufacturer at their cost and at the plant's convenience shall correct vibration exceeding these allowable levels.

Table A-9
Minimum Acceptance Criteria for Unit Absolute Vibration

For 3600 rpm Units	Vertical Vibration (Upward Side of Rotation)		Horizontal Vibration	
Location of Vibration	**At Critical Speeds**	**At 3600 rpm**	**At Critical Speeds**	**At 3600 rpm**
Journals	3-4 mils	2-3 mils	5-6 mils	3-4 mils
Bearings	2 mils	1 mil	2 mils	1.5 mils
Couplings	4-5 mils	3-6 mils	5-6 mils	3-6 mils
Collector Rings	4-5 mils	3-5 mils	5-6 mils	3-5 mils

For 1800 rpm Units	Vertical Vibration (Upward Side of Rotation)		Horizontal Vibration	
Location of Vibration	**At Critical Speeds**	**At 1800 rpm**	**At Critical Speeds**	**At 1800 rpm**
Journals	5-6 mils	3-4 mils	5-6 mils	3-5 mils
Bearings	2 mils	1 mil	2 mils	1.5 mils
Couplings	5-6 mils	5-7 mils	5-7 mils	5-7 mils
Collector Rings	5-6 mils	4-6 mils	5-7 mils	4-6 mils

6. A complete record of field balance work during startup shall be provided prior to contract sign-off. It shall include, as a minimum, running speed vibration amplitude and phase angle, filter out vibration amplitude, frequency scans at all turbine-generator-exciter bearings, and any other information taken by the manufacturer to ensure that the unit is properly designed.

9.6 OPERATING ROTOR DYNAMIC CRITERIA

1. Shaft vibration vector shifts after correction for slow-speed run-out and associated with rotor modal influences, shaft thermal stability, or any other factor involved with the replacement LP rotor shall not exceed 2 mils when plotted on polar graph paper. Any rotor dynamic factor that causes vector turning is unacceptable.

2. Rotor dynamic problems or instabilities at running speed, multiples of running speed, or sub-harmonics of running speed shall be corrected by the supplier at their cost, and on an expedited basis. The plant or its representatives shall mutually agree upon any modifications or corrective actions.

3. In the event vector turning, rotor dynamic problems, or instabilities as described should occur, the supplier shall provide, at no cost, sufficient drawings or other information of the rotors and bearings prior to contract sign-off such that mass and stiffness matrices can be developed for each shaft and stiffness and damping terms can be developed for each bearing.

4. The plant or its representatives shall mutually agree upon any modifications or corrective actions. If the required actions do not correct the problem, the buyer reserves the right to require the supplier to replace the rotor at their cost and shall include opening/closing of the unit.

9.7 SCHEDULE FOR REQUIRED DOCUMENTATION

Unless otherwise indicated in their response, the supplier will provide the required documentation associated with inspection, alignment, and balancing in accordance with the schedule as shown in Table B-10.

Table A-10
Inspection, Alignment, and Balancing Documentation

Reference	Documentation	Supplied with Bid	Prior to Assembly	Prior to Shipping	Prior to Startup	Conclude Contract
9.1.1	Notable signs of prior damage or wear				X	
9.1.2	Cleaning and inspection report on parts to be re-used and/or reinstalled				X	
9.2.1	Expected centenary/ coupling alignment changes	X				
9.2.2	Alignment correction instructions and drawings			X		
9.3.4	Detailed plan of any rotor torsional response tests	X				
9.3.5	Results of torsional frequency calculations			X		
9.4.7	Results of rotor high-speed balancing				X	
9.5.6	Record of balance work performed at startup					X
9.6.3	Sufficient drawings and information to resolve rotordynamic problems after the rotor is installed					X

10.5 SCHEDULE FOR REQUIRED DOCUMENTATION

Unless otherwise indicated in their response, the supplier will provide the required documentation associated with performance improvements in accordance with the schedule as shown in Table B-11.

Table A-11
Performance Improvement Documentation

Reference	Documentation	Supplied with Bid	Prior to Assembly	Prior to Shipping	Prior to Startup	At contract conclusion
10.1.1	Identified design enhancements and estimates of improvements to overall performance	X				
10.1.2	Itemized changes or modifications expected to improve unit reliability or maintainability	X				
10.2.1	Details of the turbine performance test plan			X		
10.2.2	Copy of the heat rate test measurements					X
10.4.2	Copy of the calculated test results					X

ATTACHMENTS 1-10

The following attachments provide checklists of the terms, conditions, and technical criteria identified throughout the rotor procurement package. Any terms, conditions, or technical criteria summarized on these checklists are referenced to the appropriate section of the bid package where they are stated in their complete form.

Potential suppliers are requested to complete these forms and return them as part of their response. Associated with the technical criteria is additional documentation that is to be provided by the supplier as part of the rotor replacement program. Note that certain documentation should be supplied with the bid.

Each attachment provides for the supplier to identify and state exceptions to any of the terms, conditions, or technical criteria. Exceptions should be referenced to the appropriate number and stated in the bid.

Responses are not limited to these forms. Potential suppliers are encouraged to include any information that is relevant to the scope of the requested purchase.

ATTACHMENT 1: COST BREAKDOWN

Page 1 of 1

Review the following checklist.
Conditions of purchase are referenced to the RFQ.
Any exceptions should be checked and an explanatory statement attached to the bid.

	PART 1- COST BREAKDOWN				**PART 2 – ADDITIONAL**	
1	LP ROTOR COST			1-A	COST OF SPARE	
a.	1^{st} LP rotor cost (manufacture/assembly/inspection)	$		a.		$
b.	2^{nd} LP rotor cost	$		b.		$
c.	3^{rd} LP rotor cost	$		c.		$
	Sub Total (1)	$		d.		$
2	STATIONARY COMPONENT COST			e.		$
a.	1^{st} stage component	$		f.		$
b.	2^{nd} stage component	$		g.		$
c.	3^{rd} stage component	$			Sub Total (1-A)	$
d.	4^{th} stage component	$				
e.	5^{th} state component	$		1-B	MODIFICATION/PARTS	
f.	6^{th} stage component	$		a.		$
g.	Other: Spedify	$		b.		$
	Sub Total (2)	$		c.		$
3	OFF-SITE COST			d.		$
a.	High-speed balance of rotor	$		e.		$
b.	Other: Specify	$		f.		$
	Sub Total (3)	$		g.		$
4	ON-SITE COST				Sub Total (1-B)	$
a.	Training and preparation	$				
b.	Disassembly of section	$		1-C	ADDITIONAL COSTS	
c.	Installation of rotor/stationary components	$		a.		$
d.	Alignment of unit	$		b.		$
e.	Slow-speed balance	$		c.		$
f.	Performance test	$		d.		$
g.	Other: Specify	$		e.		$
	Sub Total (4)	$		f.		$
				g.		$
5	TOTAL COST OF PROJECT	$			Sub Total (1-C)	$
a.	Bonus/penalty for early delivery	$				
b.	Bonus/penalty for early installation and unit startup	$			Additional terms or conditions associated with pricing should be	

ATTACHMENT 2: CHECKLIST OF WARRANTY CRITERIA

Page 1 of 1

Review the following checklist.
Conditions of purchase are referenced to the RFQ.
Any exceptions should be checked and an explanatory statement attached to the bid.

	CONDITION OF PURCHASE	**CRITERIA**	
1.1.1	Rotor(s)	30 calendar years	1.1 General Criteria
1.1.2	Rotating and stationary components	5 years, 40,000 hrs, or 1000 starts	
1.1.3	Increase in generator output	5,000 Kilowatts	
1.1.4	Manufacture period	18 months or less	
1.1.5	Installation period	8 weeks or less	
1.1.6	Acceptable rotor types	Monoblock or welded disk	
1.1.7	Installation completed	2006 outage – starts 6/1/06	
	CONDITION OF PURCHASE	**PENALTY IMPOSED**	
1.2.1	Delivery of shipment to plant	$ __________/day of delay	1.2 Liquidated Damages
1.2.2	Missing documentation	$ __________/document	
1.2.3	Exceed installation period	$ __________/additional day	
1.2.4	Corrective measures	At manufacturer's cost:	
a.	Problems with performance of any components	To include opening/closing costs	
b.	Failure of any supplied components	During mutually acceptable outage	
c.	Failure of applied modifications or fixes	Replace with new rotor	
d.	Rotor dynamic, balancing, instability problems	Supply drawings	
e.	If failed to meet technical criteria	Replace with new rotor	
	CONDITION OF PURCHASE	**PENALTY IMPOSED**	
1.3.1	Fail to increase generator output	$ __________per KW	1.3 Performance
1.3.2	Maximum liquidated costs	$ __________ or price of rotor	
1.3.3	Corrective measures	At manufacturer's cost	
a.	Additional tests to determine cause		
b.	Single opportunity to make corrections		
c.	If corrections also fail within two weeks	Penalty in effect	
	OVERALL CONTRACT RESPONSIBILITIES		
1.4.1	The supplier is responsible for training, scheduling, supervision, and technical support for the replacement.		1.4 Supplier Responsibilities
1.4.2	The supplier is responsible for labor, tools, and equipment to remove and replace rotors.		
1.4.3	The supplier will provide a detailed manufacturing schedule and provide it to the plant in electronic format.		
1.4.4	The maintenance and management schedule is to be updated every two weeks.		
1.4.5	Any variations due to non-conformance are to be reported and require plant agreement.		
1.4.6	A detailed installation plan is to be supplied to the plant no later than six months before the outage.		
1.4.7	Scheduled meetings are to be held at the plant to review progress on all major items.		
1.4.8	Visits to the supplier's facilities shall be scheduled to witness milestones.		

ATTACHMENT 3: MILESTONE SCHEDULE

Using the following list, indicate when each is to be completed.
Any times indicated are recognized as best estimates.
Any exceptions or relevant issues should be noted.

	MILESTONES FOR MANUFACTURE AND DELIVERY	Week No.
1	Placement of order	1
2	Selection and testing of forging and bar stock materials	
3	Manufacture and NDT/QC of rotor	
4	Manufacture of buckets and attachment parts	
5	Manufacture of stationary components	
6	Frequency testing of individual buckets	
7	Moment weighing of buckets	
8	Completion of rotor assembly/documentation	
9	Shot peening/surface finishing of parts	
10	Final QA/QC inspection of all parts	
11	High-speed balancing of new rotors	
12	Shipment of rotor/stationary components to site	
13	Shipment of tools to site	
14	Removal of original rotors	
15	Preparation of sections for new rotor/stationary components	
16	Installation of new rotors and stationary components	
17	Final inspection of new rotors	
18	Alignment of unit	
19	Slow-speed balancing of new rotors	
20	Removal of equipment	
	CHANGES/EXCEPTIONS	

ATTACHMENT 4: CHECKLIST OF GENERAL CRITERIA Page 1 of 1

Review the following checklist.
Conditions of purchase are referenced to the RFQ.
Any exceptions should be checked and an explanatory statement attached to the bid.

Ck if Exception	Reference	Reference: Section 3. General Criteria – Statement of Compatability Reference: Section 4. Codes and Standards	
		Reference: Section 3 – General Statement of Compatability	
	3.	The rotors are to be compatible with existing steam path and components.	
	3.	Replacement with rotors will result in no significant operational changes.	
	3.	The new rotors will have no impact on the existing feedwater heaters used in LP sections.	
	3.	Rotor replacement will result in no abnormal stresses in the rotating components.	
	3.	The new rotors will place no new limitations on plant operations, maintenance, safety, etc.	
		Reference: Section 4 – Codes and Standards	
	4.	The list of itemized codes and standards will apply to all parts purchased.	
	4.	All materials used by the supplier will meet local, state, and federal standards.	
	4.	The supplier will be responsible for all QA/QC performed by subcontractors or vendors.	
	4.	Correction for non-compliance to final standards will be at the convenience of the buyer.	
	4.	Requirements associated with codes and standards will remain in effect for 10 years.	
		Itemized Codes and Standards	
	a.	A275/A275M-98	Standard Test Method for Magnetic Particle Examination of Steel Forgings.
	b.	A276-00a	Standard Specification for Stainless Steel Bars and Shapes
	c.	A314-97	Standard Specification for Stainless Steel Billets and Bars for Forging
	d.	A370-97a	Standard Test Methods and Definitions for Mechanical Testing of Steel Products
	e.	A418-99	Standard Test Method for Ultrasonic Examination of Turbine and Generator Steel Forgings
	f.	A470-01	Standard Specification for Vacuum-Treated Carbon and Alloy Steel Forgings for Turbine Rotors and Shafts
	g.	A472-98	Standard Test Method for Heat Stability of Steam Turbine Rotor Shafts and Rotor Forgings
	h.	A473-01	Standard Specification for Stainless Steel Forgings
	i.	A484/484M-00	Standard Specification for General Requirements for Stainless Steel Bars, Billets, and Forgings
	j.	A582/A582M-95b	Standard Specification for Free-Machining Stainless Steel Bars
	k.	A751-96	Standard Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products
	l.	A768-95	Standard Specification for Vacuum-Treated 12% Chromium Allow Steel Forging for Turbine Rotors and Shafts
	m.	E353-03(200)e1	Standard Test method for Chemical Analysis of Stainless, Heat Resisting, Maraging, and Other Similar Chromium-Nickel-Iron Alloys

ATTACHMENT 5: CHECKLIST OF TECHNICAL CRITERIA

Page 1 of 1

Review the following checklist.
Conditions of purchase are referenced to the RFQ.
Any exceptions should be checked and an explanatory statement attached to the bid.

Ck if Exception	Reference	Reference: Section 5. Technical Crieria – Rotor Forging	Documentation: Sign-Off	Pre-Startup	Pre-Shipping	Pre-Assembly	Upon Award	With Bid
		Reference: Section 5.1 – Materials, Design, and Loads						
	5.1.1	Identify the forging supplier. The forging is to be in accordance with ASTM A470 Class 6 standards.						X
	5.1.2	Specimens from the forging are to be tested. The forging is to achieve superclean properties in accordance with specified limits.						
	5.1.3	Supply a sketch/drawing to show locations where specimens are obtained from the forging.				X		
	5.1.4	A method to test properties and composition will be in accordance with ASTM A370.						
	5.1.5	Test results are to be provided, showing compliance with the criteria.				X		
	5.1.6	Identify and provide maximum allowable wheel/steeple stress limits for each row.					X	
	5.1.7	Provide a 1/5th scale drawing of the rotor and rim loads.					X	
	5.1.8	Provide FE-derived wheel/steeple results for review.					X	
		Reference: Section 5.2 – Manufacturing and Processing Criteria						
	5.2.1	Forging is to be provided without a bore. Provide UT results if boring is recommended.				X		
	5.2.2	One heat treatment cycle is allowed to achieve mechanical properties.						
	5.2.3	Stress relief is not allowed after machining. The heat treatment record is to be supplied.				X		
	5.2.4	The heat stability test is to be performed in accordance with ASTM A472. Results are to be supplied.				X		
	5.2.5	Radial trepans for Charpy notch test are to be oriented in accordance with ASTM A370.						
	5.2.6	Provide recommendations/requirements for any coating/shot peening to the rotor.						X
	5.2.7	Provide details and results of any coating/shot peening performed on that rotor.				X		
		Reference: Section 5.3 – NDT and QC Criteria						
	5.3.1	No clusters are to be greater than 0.0625" in the machined forging.						
	5.3.2	Provide details on planned NDE tests and equipment used to inspect the forging.						X
	5.3.3	Ultrasonic tests are to be according to ASTM A418-87 (minimum). Results are to be provided.				X		
	5.3.4	Magnetic particle tests are to be according to ASTM A275/275M-98. Results are to be provided.				X		
	5.3.5	The forging shall not be bored without the results of tests and the approval of the buyer.						
	5.3.6	If the forging has a bore, the results are to be provided to show that cluster indications meet the standards as specified.						
		Reference: Section 5.4 – Non-Conformance						
	5.4.1	A rotor that exceeds standards/criteria because of NC shall be scrapped.						
	5.4.2	The plant shall be advised of and approve any NC-related issues that can be corrected.				X		
	5.4.3	The supplier shall provide a detailed record of any NCR issues approved and implemented.			X			

ATTACHMENT 6: CHECKLIST OF TECHNICAL CRITERIA

Review the following checklist.
Conditions of purchase are referenced to the RFQ.
Any exceptions should be checked and an explanatory statement attached to the bid.

Ck if Exception	Reference	Reference: Section 6. Technical Criteria – Rotating Buckets/Blades	Documentation: Sign-Off	Pre-Startup	Pre-Shipping	Pre-Assembly	Upon Award	With Bid
		Reference: Section 6.1 – Materials, Design, and Loads						
	6.1.1	Provide a list of basic features, row configuration, and materials. (Use the table on the next page.)						X
	6.1.2	Provide the name/address of the material stock supplier and/or blade manufacturer.						X
	6.1.3	All materials/mechanical properties are to be in accordance with ASTM codes and standards.						
	6.1.4	Cross section C of G for all blades <8" is to be within 0.062" radius axial and tangential direction.						
	6.1.5	Cross section C of G for all blades >8" is to be within 0.186" radius tangential, 0.062" radius axial.						
	6.1.6	All nominal running speed factors of safety in all rows are to be within specified limits.						
	6.1.7	FEA results are to be supplied where exception is taken to design factors of safety.					X	
	6.1.8	Blades >12" have a minimum 10-hz operating margin for the first four fundamental modes.						
	6.1.9	Design frequency margins are to be documented with Campbell and interference diagrams.				X		
	6.1.10	L-1 and L-0 are to be designed for a maximum of 10" Hg back pressure without stall or flutter occurring.						
	6.1.11	Freestanding designs will be mix-tuned to reduce the potential for flutter.						
		Reference: Section 6.2 – Manufacturing and Processing Criteria						
	6.2.1	Provide test certificates for the material. Show compliance with the supplier's standards.						
	6.2.2	No flame hardening of leading edges is to be done. (Specify if otherwise.)				X		
	6.2.3	Identify if shot peening, coating, or brush seals are used on any rows.						X
		Reference: Section 6.3 – NDT and QC Criteria						
	6.3.1	No visible deterioration is to be allowed on parts, for example, cracks, dents, missing metal, or corrosion.						
	6.3.2	Blades are to be NDE tested for flaws or cracks. Test results are to be provided to the plant.				X		
	6.3.3	Records of any shot peening performed on parts are to be provided to the plant.				X		
	6.3.4	Blades are to be moment weighed with the moment weights recorded on the assembly chart.			X			
	6.3.5	Frequencies of individual blades for each row are to be measured, tabulated, and reported.				X		
	6.3.6	Spin pit/telemetry tests are to be performed for any new blade designs (with no field experience).			X			
		Reference: Section 6.4 – Non-Conformance						
	6.4.1	Contacting surfaces are to be correctly sized to ensure proper contact during operation.						
	6.4.2	Blades are to be interchangeable between rotors for complementing rows.						
	6.4.3	Blades that exceed standards/criteria because of NC shall be scrapped.			X			
	6.4.4	The plant shall be advised of and approve any NC-related issues that can be corrected.			X			
	6.4.5	The supplier shall provide a detailed record of any NCR issues approved and implemented.			X			

ATTACHMENT 6: CHECKLIST OF TECHNICAL CRITERIA Page 2 of 2

Complete the following checklist.
Attach it to the bid.

Reference: Section 6: Technical Criteria – Rotating Buckets/Blades	Blade Rows	Row 7	Row 6	Row 5	Row 4	Row 3	Row 2	Row 1																
		L-0	L-1	L-2	L-3	L-4	L-5	L-6																
	Blade Materials																							
	Total Blades in Row																							
	Blades per Group																							
	Blade Root Type																							
	Linking Device (If Any)																							

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ATTACHMENT 7: CHECKLIST OF TECHNICAL CRITERIA

Review the following checklist.
Conditions of purchase are referenced to the RFQ.
Any exceptions should be checked and an explanatory statement attached to the bid.

Ck if Exception	Reference	Reference: Section 7. Technical Criteria – Stationary Components	Documentation: With Bid	Upon Award	Pre-Assembly	Pre-Shipping	Pre-Startup	Sign-Off
		Reference: Section 7.1 – Material, Design, and Loads						
	7.1.1	Any/all original stationary parts to be replaced with the new rotor are to be listed.	X					
	7.1.2	Any new stationary blades are to offer improved reliability and performance.						
	7.1.3	Materials used in stationary parts are to be prepared in conformance to ASTM standards.			X			
	7.1.4	Any alternative materials other than those specified are to be identified.	X					
	7.1.5	Certificates of material properties are to be supplied for nozzles/vanes.						
	7.1.6	Materials used in airfoils are to be selected for resistance to moisture and water erosion.						
	7.1.7	Airfoils are to be designed to maximize collection and drainage of moisture.	X					
	7.1.8	Use of any coatings, inserts, or weld buildup is to be identified and reported.	X					
	7.1.9	Any new/improved strategies to minimize leaving losses are to be identified and reported.	X					
	7.1.10	Any new/improved strategies to minimize leaving leakage are to be identified and reported.	X					
		Reference: Section 7.2 – Manufacturing and Processing Criteria						
	7.2.1	Stationary rows are to be fabricated. Any alternative method is to be identified; details are to be supplied.	X					
	7.2.2	Bars shall be hot formed. Final shaping is to be produced by removal of surface material.						
	7.2.3	Heat treatment is to be in accordance with the vendor's standard; details are to be supplied.		X				
	7.2.4	Heat treat charts are to be supplied for each bar.			X			
	7.2.5	A vane stacking diagram is to be provided and used to check the final vane profiles.			X			
	7.2.6	Nozzle halves are to be stress relieved.						
	7.2.7	Rings are to provide rigid assembly. All fixed blade elements are to be in the correct locations.						
	7.2.8	Discharge portions are to be adjusted to preclude harmful per-rev stimulus on rotating blades.				X		
	7.2.9	Results are to be provided of harmonic stimulus analysis performed for all stages > 13".				X		
	7.2.10	Alignment is to be by means of vertical and horizontal shims, with spare shims provided.					X	
		Criteria Associated with Stationary Parts Are Continued on the Next Page						

ATTACHMENT 7: CHECKLIST OF TECHNICAL CRITERIA

Review the following checklist.
Conditions of purchase are referenced to the RFQ.
Any exceptions should be checked and an explanatory statement attached to the bid.

Ck if Exception	Reference	Reference: Section 7. Technical Criteria – Stationary Components	Documentation: Sign-Off	Pre-Startup	Pre-Shipping	Pre-Assembly	Upon Award	With Bid
		Reference: Section 7.3 – NDT and QC Criteria						
	7.3.1	No visible deterioration is to be allowed on parts, for example, cracks, dents, missing metal, or corrosion.						
	7.3.2	The surface finish of stationary airfoils is to be 32 RMS on both concave/convex sides.						
	7.3.3	The exhaust edges are to conform to the stated criteria.						
	7.3.4	The total area, ±2%" of design, is to be documented by recorded pitch and throat measurements.			x			
	7.3.5	Individual throats are not to exceed ±2% of design, documented by measurements.			x			
	7.3.6	Radial heights are to be within ±0.60" of design, documented by measurements.			x			
	7.3.7	Individual throat measurements to inner/outer sidewalls are to be within ±3% of design.			x			
	7.3.8	Stationary bores are to be concentric within 2 mils, round within 5 mils, to be documented.			x			
	7.3.9	Horizontal joints shall have 95% contact in the unbolted position.						
	7.3.10	Bolting with be standard 8 threads per inch, no metric threads allowed.						
		Reference: Section 7.4 – Non-Conformance						
	7.4.1	Parts that exceed standards/criteria because of NC shall be scrapped.						
	7.4.2	The plant shall be advised of and approve any NC-related issues that can be corrected.				x		
	7.4.3	The supplier shall provide a detailed record of any NCR issues approved and implemented.				x		

ATTACHMENT 8: CHECKLIST OF TECHNICAL CRITERIA Page 1 of 1

Review the following checklist.
Conditions of purchase are referenced to the RFQ.
Any exceptions should be checked and an explanatory statement attached to the bid.

Ck if Exception	Reference	Reference: Section 8. Shipping, Coordination, and Support	Documentation: With Bid	Upon Award	Pre-Assembly	Pre-Shipping	Pre-Startup	Sign-Off
		Reference: Section 8.1 - Shipping						
	8.1.1	The supplier is responsible for the selection of the carrier and shipping arrangements.						
	8.1.2	The supplier is responsible for any lost, stolen, or damaged parts during shipping.						
	8.1.3	The supplier is to provide a part number listing for future ordering of replacement parts.				x		
	8.1.4	The supplier is to provide a list of units and contact names with similar units/parts.	x					
		Reference: Section 8.2 – Coordination, Drawings, and Tools						
	8.2.1	The supplier is to provide documents/drawings to support the installation and maintain the rotor.				x		
	8.2.2	The supplier is to identify the outage support requirements: list of tools, equipment, personnel.				x		
	8.2.3	The supplier is to provide a list of plant personnel support and shop support.				x		
	8.2.4	The supplier is to provide checklist sheets for inspections and tests during installation.				x		
	8.2.5	Upon arrival on site, the supplier is to review/revise the checklists of inspections and tests.						
	8.2.6	The supplier is to provide system information and drawings as required by the plant.						x
	8.2.7	The supplier is to provide safety and environmental instructions as required for future rotor O&M.						x

ATTACHMENT 9: CHECKLIST OF TECHNICAL CRITERIA Page 1 of 2

Review the following checklist.
Conditions of purchase are referenced to the RFQ.
Any exceptions should be checked and an explanatory statement attached to the bid.

Ck if Exception	Reference	Reference: Section 9. Inspection, Alignment, and Balancing	Documentation: Sign-Off	Pre-Startup	Pre-Shipping	Pre-Assembly	Upon Award	With Bid
		Reference: Section 9.1 – Inspection Criteria						
	9.1.1	Prior to old rotor removal, report all notable signs of wear or damage to the section.		x				
	9.1.2	Report the results of cleaning and inspection for all original parts to be re-installed.		x				
		Reference: Section 9.2 – Alignment Criteria						
	9.2.1	Provide expected cantenary and coupling changes and a plan for alignment of the unit.						x
	9.2.2	Provide alignment corrections in the instruction book and drawings.			x			
	9.2.3	Perform alignment corrections at no cost to the plant.						
		Reference: Section 9.3 – Shaft-System Torsional Resonance Response Criteria						
	9.3.1	The new system is to avoid torsional resonance at 60 hertz or 120 hertz.						
	9.3.2	The new system is to maintain a frequency margin of ±2 hertz from 60 hertz or 120 hertz.						
	9.3.3	The supplier is responsible for any modifications or testing required to meet the torsional criteria.						
	9.3.4	For any testing, the supplier is to provide a plan and report the results of torsional tests.						x
	9.3.5	If calculations are substituted for testing, the results are to be provided to the plant.			x			
		Reference: Section 9.4 – High-Speed Spin Pit and Field Balancing Criteria						
	9.4.1	Perform high-speed balance at critical speeds, running speeds, and overspeed.						
	9.4.2	The rotor is to meet all specified balancing criteria at the 1st and 2nd critical speeds.						
	9.4.3	The rotor is to operate for >30 minutes with no more than a 0.5 mil vector change occuring.						
	9.4.4	Operating above 2nd critical, the rotor is not to exceed a maximum static unbalance of 0.7 mils.						
	9.4.5	The rotor is not to exceed specified vibration criteria during roll-up/roll-down.						
	9.4.6	The results of high-speed balancing are to be provided to the plant.			x			
		Criteria Associated with Inspection, Alignment, and Balancing Are Continued on the Next Page.						

ATTACHMENT 9: CHECKLIST OF TECHNICAL CRITERIA

Page 2 of 2

Review the following checklist.
Conditions of purchase are referenced to the RFQ.
Any exceptions should be checked and an explanatory statement attached to the bid.

Ck if Exception	Reference	Reference: Section 9. Inspection, Alignment, and Balancing	Documentation: Sign-Off	Pre-Startup	Pre-Shipping	Pre-Assembly	Upon Award	With Bid
		Reference: Section 9.5 – On-Site Shaft-System Balance and Vibration Criteria						
	9.5.1	The new rotor inch-ounce balance capability is to be the same as or better than the original.						
	9.5.2	The absolute vibration of other rotors will not be impacted by the new rotors.						
	9.5.3	The maximum slow roll run-out of the new rotor shall not exceed 1 mil.						
	9.5.4	The shaft train vibration shall be less than before the rotors were replaced.						
	9.5.5	The specified allowable vibration levels shall be achieved at no cost to the plant.						
	9.5.6	The supplier is to provide a complete record of the balance work performed during startup.	x					
		Reference: Section 9.6 – Operating Rotor Dynamic Criteria						
	9.6.1	The shaft vibration vector shifts are not to exceed 2 mils after correction.						
	9.6.2	Any new dynamic problems or instabilities shall be corrected at no cost to the plant.						
	9.6.3	The supplier is to provide drawings as required to solve rotor dynamic/instability problems.	x					
	9.6.4	The supplier is to replace the rotor if modifications or corrective actions fail to work.						

ATTACHMENT 10: CHECKLIST OF TECHNICAL CRITERIA

Page 1 of 1

Review the following checklist.
Conditions of purchase are referenced to the RFQ.
Any exceptions should be checked and an explanatory statement attached to the bid.

Ck if Exception	Reference	Reference: Section 10. Performance Improvements	Documentation: Sign-Off	Pre-Startup	Pre-Shipping	Pre-Assembly	Upon Award	With Bid
		Reference: Section 10.1 – Design Modifications						
	10.1.1	The supplier is to tabulate any design modifications and estimate efficiency improvement.						x
	10.1.2	The supplier is to tabulate any modifications expected to improve maintainability/reliability.						x
		Reference: Section 10.2 – Test Criteria						
	10.2.1	Testing is to be performed according to ASME PTC-6 (AM). Provide the details of the test plan.						x
	10.2.2	The heat rate is to be based on three tests before and after replacement. Provide the test results.	x					
	10.2.3	No uncertainty factors are to be applied to heat rate tests.						
	10.2.4	Bonus/penalty beyond guarantees is to be negotiated prior to the contract award.						
	10.2.5	Any subsequent tests to demonstrate guarantees will be at no cost to the plant.						
		Reference: Section 10.3 – Test Setup						
	10.3.1	High accuracy instrumentation will be used to perform tests.						
	10.3.2	Primary flow will be measured with plant instrumentation.						x
	10.3.3	Sixteen total pressure measurements are to be made at the locations specified.			x			
	10.3.4	Twenty-seven temperature measurements are to be made at the locations specified.						
	10.3.5	Seven differential pressure measurements are to be made at the locations specifed.						
	10.3.6	Electric ouput is to be measured with calibrated transformers installed prior to the tests.						
		Reference: Section 10.4 – Calculation of Test Results						
	10.4.1	For calculating test results, the unit will operate one hour before and after data are taken.						
	10.4.2	The heat rate will be corrected by use of generic correction curves. The results will be reported to the plant.	x					
	10.4.3	Corrections (Group 1 and 2) will be made in accordance with the specification.			x			
	10.4.4	The cycle isolation list will be developed and agreed upon prior to testing.						
	10.4.5	During tests, specified systems are to be isolated.						
	10.4.6	During overhaul, a thrid-party steam path audit will be used to establish a baseline.		x				

Modify + include as part of the specs

1

STEAM TURBINE BLADE/BUCKET PROCUREMENT GUIDELINES

This section provides a general guideline of the technical requirements recommended to guide the purchase of fossil plant steam turbine buckets. As part of the procedure, a list of requirements is recommended in association with any reverse engineering or engineering analysis that is performed and for any manufacturing drawings that are supplied along with the procured components. Documentation associated with the manufacturing and ~~quality control~~ checks made of the delivered components is also specified to ensure that the final product complies with the requirements identified in the engineering procedure.

The procedure itself is designed to be generic in nature and to account for different possible procurement scenarios. The engineer responsible for any procurement of buckets/blades is expected to tailor this procedure according to the situation or the type of supplier that is solicited to provide a bid. An example of such a bid package to obtain a row of blades/buckets is provided in Appendix A. For example, if the buckets/blades are to be procured through a third-party (Non-OEM) supplier, the requirements associated with the reverse engineering and engineering analysis within this procedure should be included. The requirements associated with the process of reverse engineering are designed to ensure that the dimensions used to prescribe manufacturing tolerances are taken from enough samples to sufficiently represent those used in the original.

General Requirements associated with the engineering analysis are specified to provide critical information on frequencies, operating stresses, and fatigue life. **Subrequirements** specify further actions that should be undertaken to check locations where the predicted stress exceeds the general requirement.

As shown in Figure 1-1, stresses are required at key locations in the design to indicate whether they are expected to approach or exceed the yield strength of the material (and therefore may be susceptible to low cycle fatigue [LCF]) or the endurance limit of the material (high cycle fatigue [HCF]). Frequencies for the first four fundamental modes are requested in order to show the margin of tuning and the margin from resonance that the assembled row can be expected to achieve. Tables are attached to assist potential suppliers in identifying the information that is requested under each separate requirement. Having the potential suppliers tabulate their responses in this manner makes it clear what level of detail is being requested and ensures the results are supplied in a consistent format.

It is recommended that third-party suppliers should be asked to comply with all of the basic requirements of this procedure. It is also desirable that original equipment suppliers (OEMs) comply with this procedure, although this may be subject to some negotiation. However, if an original design has been modified to improve stage efficiency or correct a reliability problem, a structural analysis of the new design should then be specified as a requirement, even from an OEM.

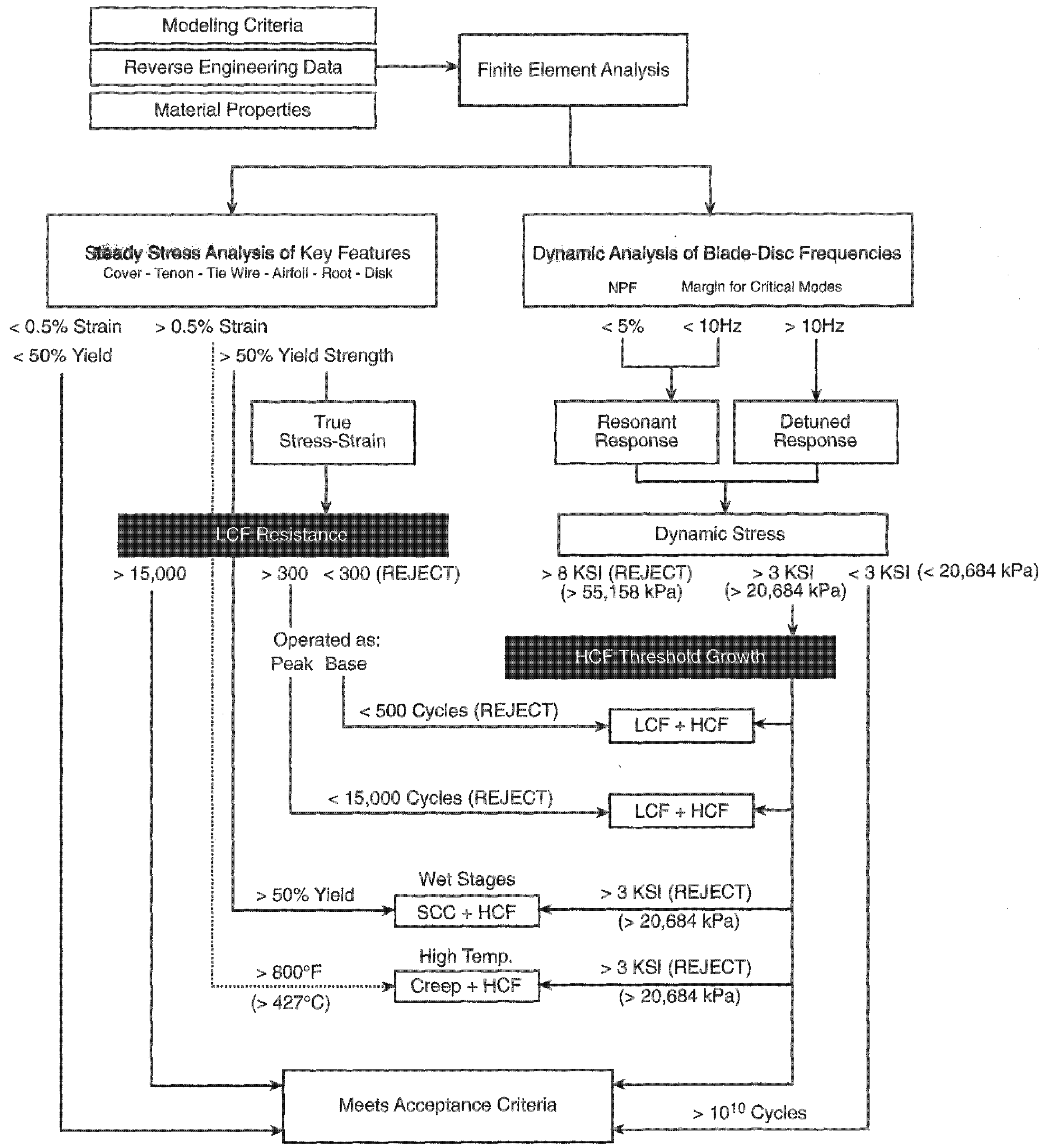

Figure 1-1
Design Audit Procedures and Recommended Acceptance Criteria

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Nomenclature used throughout this procedure referring to different structural features of a bucket is identified in Section 1.9 and illustrated in Figure 1-2.

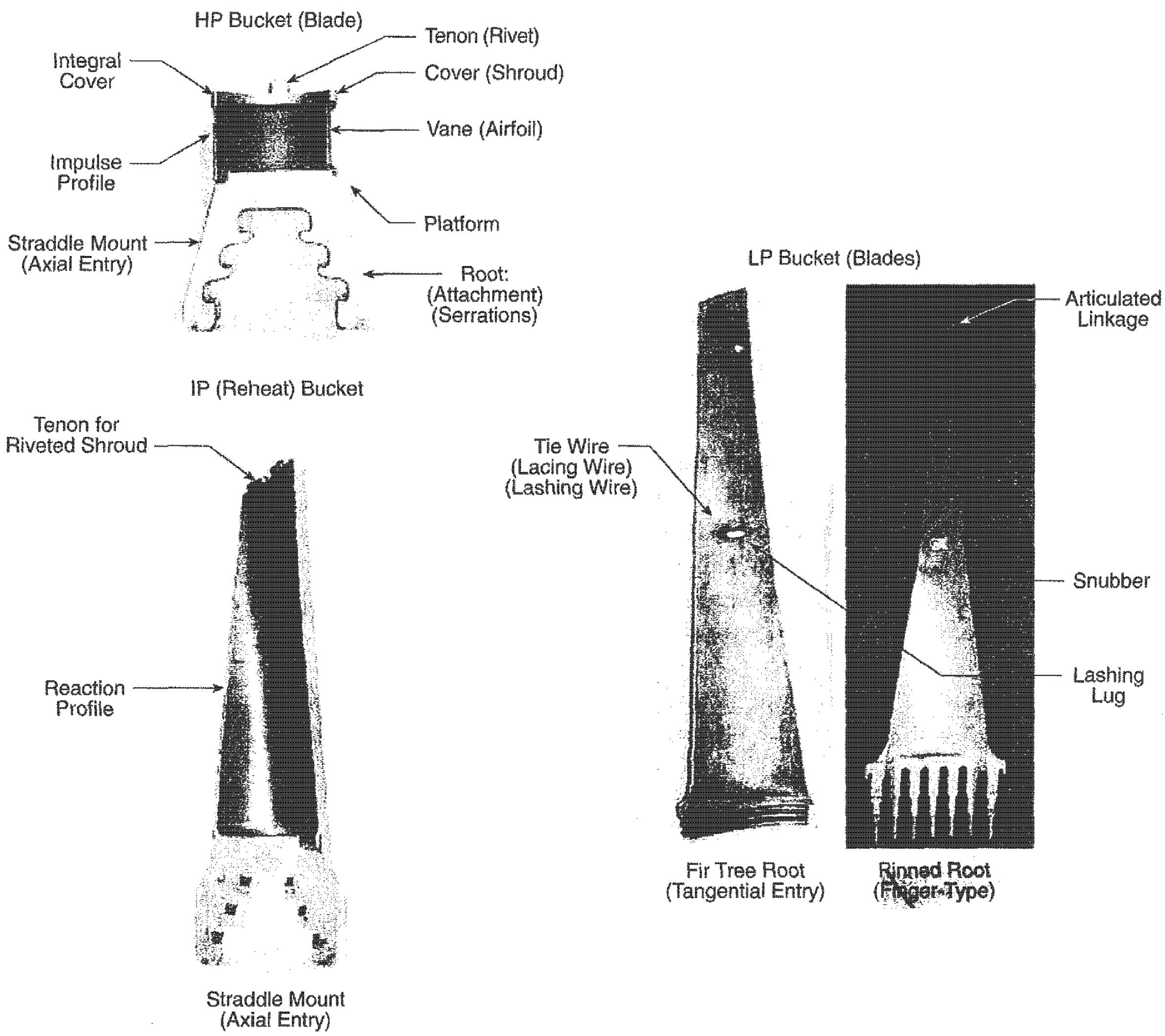


Figure 1-2
Blade/Bucket Nomenclature Identification

The following list contains requirements for blade/bucket suppliers:

1. This procedure defines a list of technical requirements for the supply of a row of steam turbine buckets. The acceptance requirements prescribed within this procedure are to become part of a warranty on the new components.

2. The procedure includes the completion of the tables that define features of the supplier's product. The details supplied in response to this procedure should form the basis for accepting the final delivery of the components, if the supplier is awarded the contract.

3. The replacement buckets should (a) be completely compatible with the present turbine steam path components, (b) result in no detrimental changes when compared against the unit operation with the present components, and (c) place no serious limitations on the operation, maintenance, or safety requirements of the plant.

4. Any modifications to existing rotors, stationary parts, bearings, etc. to achieve item 3 should be identified and included in the overall proposed cost.

5. Any unplanned modification or work required at the installation of the blades due to design or manufacturing error will be at the supplier's expense.

6. If the components supplied under this procurement procedure are to be obtained by reverse engineering of specimens, then all analysis, models, and drawings used to produce the blades will be supplied with the parts in accordance with the requirements set forth within this procedure.

7. If the blades supplied under this procurement procedure are of an original design, then the manufacturer will agree to provide, upon receipt of a letter of intent to purchase, sufficient details to allow independent finite element (FE) modeling and analysis of the modified design by the purchaser or a qualified third-party consultant. Exchange and/or use of any proprietary information required to complete the independent analysis will be conducted under mutually accepted conditions of confidentiality.

8. Upon selection of a final supplier, a letter of intent to purchase will be issued based on the response to the information requested within this procurement procedure.

1.1 Reverse Engineering

Critical Dimensions

1.1.1 General Requirement: Geometry and Dimensions

- If the geometry and dimensions of the components are to be reverse engineered from an original design, measure a minimum of 10 blade samples to establish the design parameters from a range of measured tolerances. Average all dimensions obtained from the 10 samples. Reflect this average on final machining and manufacturing drawings.
- Table 1-1 represents a minimum of information to report in order to document how key dimensions and tolerances were established. Supply the final parameters to the purchaser for review and approval before manufacturing commences.
- Identify by type and manufacturer the coordinate measurement system and any tools applied to reverse engineer dimensions from the samples. All devices used to reverse engineer dimensions from original samples must perform measurements with an accuracy of 0.002" (0.0508 mm).

1.1.2 General Requirement: Structural Features

1. As a minimum, measure design features of the bucket in accordance with the criteria identified in Subrequirements 1.1.2.1 through 1.1.2.5.

2. For longer blades, measure the moment weight of individual blades, and make a determination of the most appropriate distribution of the blades around the rotor rim to minimize the total "out of balance" forces that need to be balanced. Provide moment weight data in the form of a drawing or other method and deliver it as part of the blade supply. Measured blade weight must be accurate to the nearest 0.01 lb.-in. (115.21 g-mm).

1.1.2.1 Subrequirement: Tenons

1. Determine dimensions describing any tenon from the coordinates measured from no less than three points taken along each straight or curved line segment that makes up the overall geometry.

2. A filet radius is required where the tenon joins the main profile in which no discontinuities or surface tears will be acceptable.

3. Sufficient material to form the tenon head should be available to be certain that the cover band will be fastened tight to the tip platform resulting in gaps under the cover band that do not exceed 0.005" (0.127 mm) on the inlet edge or 0.003" (0.0762 mm) on the discharge side.

4. The tenon head (after peening) should have no steps or indentations on its surface.

1.1.2.2 Subrequirement: Cover

1. Determine dimensions describing any cover from the coordinates measured from no less than three points taken along each straight or curved line segment that makes up the overall geometry.

2. Chamfer the underside of band holes. When circular tenons are used, the underside of the band holes must be chamfered or have a radius sufficient to prevent interference between the tenon and the underside of the cover band filet radius or chamfer.

3. Cover bands are to have chamfers on both the inner and outer edge of the tenon hole. Remove any burrs from this chamfer.

4. The inner chamfer of the tenon hole must be sufficiently large enough to prevent interference between the cover and tenon filet radius.

1.1.2.3 Subrequirement: Tie Wire/Lashing Lug

1. Measure dimensions used to describe any lashing lug or device used to tie blades together in no less than 0.001" (0.0254 mm) increments.

2. For non-circular lugs, obtain cross-sectional measurements at no less than six locations to represent the geometry.

3. Where floating tie wires are used, drill the position of the vane hole relative to the root to ensure correct alignment.

4. Chamfer or round off all hole corners in accordance with the original design form.

5. If the wire is brazed to the blade vane, control the quantity of material in accordance with the original design form.

6. After brazing, remove excess braze material from the wire and vane. Clean the area around the braze joint with an emery cloth after fusion is complete.

7. If welding is used to attach or connect stubs, apply pre- and post-weld heat treatment in accordance with the original design heating and cooling rates.

1.1.2.4 Subrequirement: Airfoil

1. Obtain coordinates for a minimum of three cross-section profiles or at every 3.0" (7.62 cm) increment along the entire airfoil height (that is, from platform to cover) for each of the 10 samples.

2. For each of these individual cross sections, measure a minimum of 200 points to fully describe the entire circumference of the profile.

3. Out of these 200 total points, use no less than 30 points to describe the shape of either the leading edge or the trailing edge radius of the profile.

4. As a minimum requirement, measure the fillet radii at the platform (where the airfoil joins the platform) at 1.0" (2.54 cm) intervals on both the concave and the convex sides.

5. Take a minimum of three fillet radii measurements at both the leading edge and the trailing edge.

6. Apply the same requirements to establish the fillets of an integral cover.

7. Allow only a plus tolerance in discharge tail thickness to ensure against local thinning.

1.1.2.5 Subrequirement: Root Attachment

1. Take dimensional coordinates on a cross-section profile that is normal to the direction of the root serrations. Nomenclature is identified in Figure 1-3.

2. Use a minimum of five points to describe any curved or straight segment along the entire circumference of the cross-section profile.

3. For a straddle-mount/tangential-entry root, define any curvature by five data points taken along each hook, measured in the tangential direction [1].

1.1.3 Administrative Requirements

The vendor, supplier, or OEM should provide the information in Table 1-1 to the designated utility representative.

Table 1-1
Record of Basic Dimensions from Samples

Number Samples		**Minimum 10 Samples To Be Measured**								
Accuracy of System Used:		Accuracy to 0.002" (0.0508 mm) Specified								
Measurement System Used:		Model and Type of Commercial System:								
Locations	**Sample Numbers 1 Through 10**									
Total Blade Height										
Maximum Blade Width										
Filet at Blade Platform										
Cover Thickness										
Cover Width										
Cover Length										
Chamfer (Inner/Outer Edge)										
Tenon Width										
Tenon Length										
Tenon Height										
Tenon Fillet Radius										
Inlet Nose Radius at Height 1										
Profile Chord at Height 1										
Profile Thickness at Height 1										
Discharge Tail Thickness at Height 1										
Inlet Nose Radius at Height 2										
Profile Chord at Height 2										
Profile Thickness at Height 2										
Discharge Tail Thickness at Height 2										
Inlet Nose Radius at Height 3										
Profile Chord at Height 3										
Profile Thickness at Height 3										
Discharge Tail Thickness at Height 3										

Table 1-1 (cont.)
Record of Basic Dimensions from Samples

Number Samples		**Minimum 10 Samples To Be Measured**								
Accuracy of System Used:		Accuracy to 0.002" (0.0508 mm) Specified								
Measurement System Used:		Model and Type of Commercial System:								
Locations	**Sample Numbers 1 Through 10**									
Total Root Width										
Width – Between 1st Hook Pair										
Width - Load Bearing 1st Pair										
Radius – Above 1st Pair										
Spread – Between 1st and 2nd										
Width – Between 2nd Hook Pair										
Width -Load Bearing 2nd Pair										
Radius – Above 2nd Pair										
Spread – Between 2nd and 3nr pair										
Width – Between 3rd Hook Pair										
Width -Load Bearing 3rd Pair										
Radius – Above 3rd Pair										

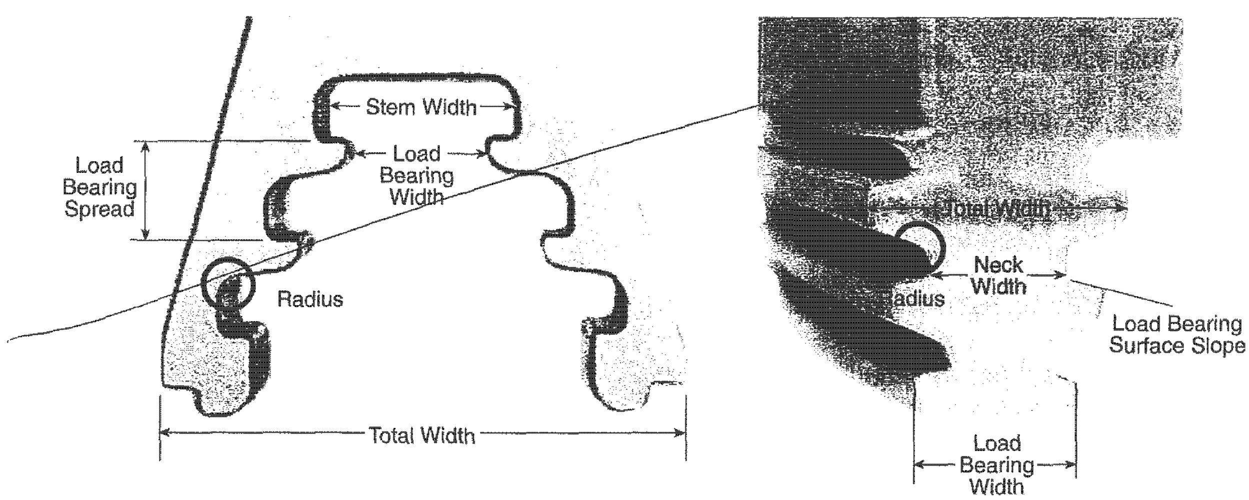


Figure 1-3
Nomenclature Used in Root Dimensional Measurements

Show Pinned Root (finger-type)

1.2 Manufacturing Drawings

1.2.1 General Requirement: Drawings

1. Provide any manufacturing drawings that must furnished with the buckets as AutoCAD or PRO-ENGINEERING files.
2. Prepare drawings in accordance with ANSI standards.
3. Drawings should identify all dimensions as specified in Section 1.1 and listed in Table 1-1.
4. Reflect a minimum ±0.002" (0.0508 mm) tolerance for all general dimensions, with the exceptions identified in Section 1.1.2 (General Requirements) and Sections 1.1.2.1 through 1.1.2.5 (Subrequirements).
5. Before manufacturing begins, provide for review and final approval any drawings to be furnished with the replacement buckets.

1.2.2 General Requirement: Detailed Information

1. Specify airfoil profiles by no less than 200 digitized points.
2. Any drawing of the root should specify tolerances for the load bearing lands and allowable clearances to the disc.
3. Where a notch blade is used, provide an assembly drawing along with allowable clearances.
4. Provide any platform pins with an allowable tolerance of interference.
5. Reflect procedures for any tang rolling on the final manufacturing drawings.

1.3 Tolerances and Surface Finishes

1.3.1 General Requirement: Tolerance Limits

1. Before components are shipped, individually measure them and check then to ensure their conformity to target tolerances identified against critical features of the design. Check and document buckets provided under this procedure using the format identified in Table 1-1.
2. The maximum allowable deviation from any general tolerances or coordinates identified on the manufacturing drawings is ±0.002" (0.0508 mm), except for the root attachment and integral cover shown in Table 1-2.
3. Indicate (on any milestone schedule supplied with a response to this procedure) the delivery of the tolerance check results.

Table 1-2
Allowable Tolerances [1]

Region	Target	Comment
Cover	± 0.002" (0.0508 mm)	For any given general dimensional target
Integral Cover	± 0.002"	Maximum allowable gap between interfacing surfaces
Blade/Bucket	± 0.002"	Target height for any given component
Profiles	± 0.005" (0.127 mm)	Chord/thickness at tip, mid-span, and platform
Platform	± 0.002"	Radii on concave and convex sides
Root	± 0.005"	Land to land, at all bearing surfaces
Surface Finish	32 μ-inches (0.8 micro-meter)	Root hooks and vane
Surface Finish	64 μ-inches (1.6 micro-meters)	All other surfaces

1.4 Materials and Properties

1.4.1 General Requirement: Allowable Materials

1. Report the generic blade/bucket material of the original design in Table 1-3.
2. The following materials are considered acceptable for the manufacture of low-pressure turbine buckets/blades:
   - AISI 403, AISI 410 with chemical and material properties as defined in ASTM 276-92.
   - AISI 630 (17-4PH), with chemical and material properties as defined in ASTM A705
   - Ti-6A1-4V
   - Jet Heat M152 (AMS 5719)

Pull up properties

3. The following materials are considered acceptable for the manufacture of high-pressure turbine buckets/blades:
   - AISI 410
   - AISI 422
   - Carpenter H-46
4. The following materials will be considered acceptable for the manufacture of covers, tie wires, and pins:
   - Covers AISI 403, AISI 410, AISI 630 (17-4PH)
   - Tie Wires AISI 316, AISI 403, AISI 630 (17-4PH)
   - Pins AISI H11, A193, 316

5. In addition to these basic materials, the supplier can elect to offer alternatives—if they are shown to offer superior or advantageous properties and performance. Report in Table 1-3 any materials to be used other than those listed above.

6. For any substitute materials indicated in Table 1-3, identify the chemical composition in weight percentages.

Table 1-3
Materials and Their Chemical Composition

ASTM Material Used in Bucket/Blade			
ASTM Material Used in Cover			
ASTM Material Used in Tie Wires/Lashing Lugs, Snubbers, etc.			
ASTM Material Used in Root Attachment Pins			
Indicate NA (Not Applicable) If Blades are Freestanding, Have Integral Covers, and/or Are Not Pinned.			
Chemical Composition	**Bucket/Blade**	**Cover**	**Pins**
Chromium (Cr)			
Molybdenum (Mb)			
Nickel (Ni)			
Cobalt (Co)			
Manganese (Mn)			
Carbon (C)			
Sulfur (S)			
Phosphorus (P)			
Silicon (S)			
Nitrogen (N)			
Titanium (Ti)			
Other			

1.4.2 General Requirement: Mechanical Properties

1. For each of the materials that are listed in Table 1-3, identify the tensile strength, yield strength, percentage of elongation, reduction of area, hardness, Charpy V-notch, fracture toughness, and threshold stress intensity using the format shown in Table 1-4. In no instance should 400 series stainless steels be supplied with a hardness in excess of HRC 30.

2. Identify in Table 1-4 if buckets are to be produced from bar-stock or an envelope forging. Produce any forging at temperatures between 1950–2025°F (1066–1107°C) and finish it at temperatures not lower than 1550–1600°F (843–871°C).

3. Supply the information supplied in Table 1-4 in advance of the manufacture of the buckets. This information will act as the target acceptance checklist by which the mechanical properties of the material used in the final product will be tested, compared, and reported.

Table 1-4
Source of Buckets/Blades and Their Mechanical Properties

Source of Bucket Material:			**AISI:**
Bar Stock? ____Yes ____No		Envelope Forging ____Yes ____No	
Mechanical Properties	**Bucket/Blade**	**Cover**	**Pins**
Tensile Strength (ksi or MPa)			
0.2% Yield Strength (ksi or MPa)			
Elongation (%)			
Reduction of Area (%)			
Charpy V-Notch (ft-lb or N-m)			
Hardness (BHN)			

1.4.3 General Requirement: Material and Fatigue Properties

1. To support results reported from a structural analysis, report in Table 1-5 the Young's Modulus, Poisson's Ratio, and density that are used to calculate stresses and natural frequencies for each of the materials listed in Tables 1-3 and 1-4.

2. To support results where a fatigue analysis is required, report in Table 1-6 the mechanical properties that are used to calculate low-cycle and high-cycle initiation life for each of the materials listed in Tables 1-3 and 1-4.

3. To support results where an analysis of damage tolerance is required, report the stress intensity factor and threshold value for the respective components in Table 1-8 for each of the materials listed in Tables 1-3 and 1-4.

4. If buckets are to be operated in or beyond the Wilson line, list in Table 1-7 the K_{ISCC} and SCC growth rate date for each of the materials listed in Tables 1-3 and 1-4.

5. If the stage operating temperature is greater than 800°F (427°C), report in Table 1-8 the specific heat, thermal conductivity, and coefficient of thermal expansion for each of the materials listed in Tables 1-3 and 1-4.

Table 1-5
Basic Material Properties Used in Structural Analysis

Material Properties	Bucket/Blade	Cover	Pins	Disk
Young's Modulus (ksi or MPa)				
Poisson's Ratio				
Density				

Table 1-6
Additional Material Properties Used for Fatigue Life Prediction

Fatigue Properties	Bucket/Blade	Cover	Pins	Disk
Fatigue Strength Coefficient [σ'_f]				
Fatigue Strength Exponent [b]				
Fatigue Ductility Coefficient [ε'_f]				
Fatigue Ductility Exponent [c]				
Fracture Toughness (K_{IC})				
Threshold Stress Intensity (ΔK_{th})				

Table 1-7
Material Properties for Further Analysis of SCC in Wet Regions

Material Properties*	Bucket/Blade	Cover	Pins	Disk
SCC Growth Rate* [da/dt]				
SCC Threshold Value* [K_{ISCC}]				
*Not required unless the stage operates within or beyond the Wilson Line				

Table 1-8
Material Properties Used in Structural Analysis of High-Temperature Buckets

Material Properties	Bucket/Blade	Cover	Pins	Disk
Specific Heat*				
Thermal Conductivity*				
Coefficient of Expansion*				
* Not required unless the stage operating temperature is greater than 850°F (454°C)				

1.5 Erosion/Corrosion Protection

1.5.1 General Requirement: Surface Treatments

1. Report in Table 1-9 any surface treatments, such as flame hardening, shot peening, or coating, to be applied to the buckets.

2. If Yes is indicated to any of the treatments, then conformity with Section 1.5.1.1 is required.

1.5.1.1 Subrequirement: Flame Hardening/Shot Peening

1. Report in Table 1-9 the details for any planned induction hardening, flame hardening, or shot peening to the buckets.

2. Report any type of coating to be used along with the expected duration or life of the coating.

3. Report a description of the procedure and requirements for any flame hardening or induction hardening to be performed on the buckets.

Table 1-9
Erosion/Corrosion Protection

Planned Treatments	Bucket/Blade	Regions To Be Treated*
Induction Hardening	Yes - No	
Flame Hardening	Yes - No	
Shot Peening	Yes - No	
Coating	Yes - No	Est. Coating Life ___Hours
Description of Procedure:		
* Tenon, cover, airfoil leading edge, airfoil trailing edge, tie wire, root, disk attachment		

1.6 Structural Reliability – Low Cycle Fatigue

1.6.1 General Requirement: Structural Analysis Results

1. Report a summary of stress and frequency results for each type of bucket, conforming to the formats of Tables 1-10 through 1-12.

2. Material properties used as input for the structural analysis will be those in Table 1-4.

3. If dimensions are obtained by reverse engineering, provide the finite element (FE) model used to obtain stress and frequency results, along with the buckets.

4. Obtain at-speed frequency information on the first four fundamental nodal diameter (ND) mode families by FE analysis (FEA) or testing.

5. For any low cycle fatigue (LCF) or high cycle fatigue (HCF) analysis results provided as part of this procedure, attach, as an addendum, the stress-strain curve and the S-N (strain versus number of cycle to failure) curve used as input.

6. Obtain stress results by means of FE analysis in accordance with the modeling criteria specified in Section 1.6.1.1.

1.6.1.1 Subrequirement: Finite Element Modeling

1. Report in Table 1-10 the FEA program and revision number used to perform any analysis of the components.

2. Derive the stress results required in this procedure from a three-dimensional, linear-elastic FE model of a blade-disc with a FE model comprised of no less than 5000 solid elements. The element aspect ratio should be in the range of 0.2 to 5.0.

3. Use a minimum grid of 2x6 elements in the airfoil section. In modeling the root attachment, use at least two layers of elements in the hook notch fillet regions.

4. For calculating blade-disk natural frequencies and dynamic stresses, a three-dimensional 360° fully bladed disc model is required. Use no less than 12 master degrees of freedom (DOF) to represent the airfoil, that is, 6 in the tangential direction and 6 in the axial direction.

1.6.2 General Requirement: Steady Operating Stress

1. Report in Table 1-10 results from a structural analysis to summarize the maximum steady *elastic* stress (ksi or MPa) (equivalent and principal) that occurs under centrifugal loads at full speed operation for each of the key structural features of the bucket.

2. Indicate any elastically calculated stress in Table 1-10 that is greater than the material yield strength as such. These stresses should be further subject to conversion into true stress and strain in accordance with the procedures of Section 1.6.2.1. Report results in Table 1-11.

Table 1-10
Summary of Calculated Steady Stresses

FE Program Used:		Revision #	
Structural Feature Material Yield Strength ____ksi (MPa)	**Max Equivalent Elastic Stress ksi (MPa)**	**Max Principal Elastic Stress ksi (MPa)**	**Local Yielding?** Yes or No**
Cover: (Shroud/Integral)*			
Tenon*			
Tie Wire – Lashing Lug*			
Airfoil – Leading Edge			
Airfoil – Trailing Edge			
Blade Root			
Disk Attachment			
* If not applicable, indicate with NA.			
** Indicate Yes if the reported elastic stress exceeds the material yield strength.			

1.6.2.1 Subrequirement: True Stress

1. Derive true stress either by means of an elasto-plastic FE analysis of the region or by applying Neuber's approach defined as follows.

2. Define the Neuber's hyperbola by the elastic stress (σ_e) and Young's modulus (E), using Equation 1-1.

   $$\sigma_e^2 = \varepsilon \cdot \sigma \cdot E \qquad \textbf{Eq. 1-1}$$

   Couple Neuber's hyperbola with the stress-strain relationship using Equation 1-2, where E, K, and n are material stress-strain properties.

   $$\varepsilon = \frac{\sigma}{E} + \left(\frac{\sigma}{K}\right)^{1/n} \qquad \textbf{Eq. 1-2}$$

3. Obtain the true strain by solving the two equations simultaneously. Report results in Table 6-2.

4. For any analysis of fatigue damage, base mean stress on the true stress, not the elastic stress value.

Table 1-11
Calculated True Stress in Identified Regions of Local Yielding

Structural Feature	Max Equivalent Elastic Stress ksi (MPa)	True Stress ksi (MPa)**	Local Yielding?*** Yes or No
Cover: (Shroud/Integral)*			
Tenon*			
Tie Wire – Lashing Lug*			
Airfoil – Leading Edge			
Airfoil – Trailing Edge			
Blade Root			
Disk Attachment			
* If not applicable, indicate with NA.			
** Covert maximum equivalent stress using formula from Subrequirement 6.4.1			
*** Indicate Yes if the true stress still exceeds the material yield strength.			

1.6.3 General Requirement: Low Cycle Fatigue - Crack Initiation

1. Where the calculated stress exceeds the material yield strength, evaluate the crack initiation life associated with start-stop cycles (for example, LCF) of the turbine using the "local strain approach" and in accordance with Section 1.6.3.1.

2. Report results in Table 1-12.

1.6.3.1 Subrequirement: Low Cycle Fatigue Life Prediction

1. Base the calculated plastic strain amplitude *(ε_p)* and the strain versus number-of-cycles-to-failure (S-N) curve on an operating history comprised of 12,000 start-stop cycles experienced over 30 years.

2. Account for a total of one overspeed cycle per year at 110% rated speed in the number of cycles estimated to initiate cracks.

3. Identify the values used to represent both the plastic strain amplitude and S-N curve used for the LCF analysis. Use Equation 1-3 to calculate the number of start-stop cycles that the region identified as critically stressed can experience.

$$N_f = \frac{1}{2}\left(\frac{\varepsilon_p}{\varepsilon_f}\right)^{\frac{1}{c}} \qquad \textbf{Eq. 1-3}$$

Where ε_f and c are LCF growth parameters to be identified in Table 1-12.

Table 1-12
LCF Crack Initiation Life for Identified Regions of Local Yielding

Structural Feature	True Stress ksi (MPa)	Plastic Strain (ε_p)	Est. Start-Stop Cycles
Cover: (Shroud/Integral)*			
Tenon*			
Tie Wire – Lashing Lug*			
Airfoil – Leading Edge			
Airfoil – Trailing Edge			
Blade Root			
Disk Attachment			
		True fracture ductility ε_f applied:	
		Fatigue ductility exponent (c) applied:	
* If not applicable, indicate with NA.			

1.6.4 *Acceptance Criteria: Low Cycle Fatigue Life Limits*

1. All structural features should have predicted stress levels that do not exceed the material yield strength or should achieve a predicted LCF life of not less than 300 start-stop cycles. If an LCF life of less than 300 start-stop cycles is reported in Table 1-12, a modification, supported with an FE analysis, may be required to demonstrate that the modified design produces a true stress that achieves an LCF endurance limit of 300 cycles or greater.

2. For units operated in a base load mode, the LCF limit may be relaxed to 500 cycles if the predicted dynamic stress from any given mode of vibration does not exceed 3 ksi (20.685 MPa). A dynamic stress analysis as defined in Section 1.7 is required to show compliance with this criterion.

3. For a unit cycled more than 100 start-stops per year, the LCF limit should remain no less than 15,000 cycles *and* the predicted dynamic stress from any given mode of vibration also may not exceed 3 ksi (20.685 MPa). A dynamic stress analysis as defined in Section 1.7 will be required to show compliance with this criterion.

1.7 Structural Reliability - High Cycle Fatigue Interaction

1.7.1 General Requirement: Identification of Natural Frequencies

1. Identify blade-disk frequency results obtained by either calculation or testing by their nodal diameter (ND) mode family for each of the first four fundamental blade modes, and report the results in Table 1-13. Also in Table 1-13, report the nozzle passing frequency for the stage.

2. Plot the ND modes shown in Table 1-13 on a frequency interference diagram (FID), with the number of ND modes forming the abscissa of the diagram equal to the total number of blade groups in the row divided by two. Plot the frequency interference diagram and supply it as an addendum to this table.

3. For free standing buckets or an arrangement where a continuous tie is formed between the buckets, the maximum ND is equal to the number of blades divided by two.

1.7.2 Acceptance Criteria: Detuning From Resonance

1. Adequately tune all blade-disk fundamental modes shown in Table 1-13 to avoid resonance with nearest per-revolution force (or engine order). Adequate detuning is defined as having each of the calculated at-speed natural frequencies provide a margin greater than 15 Hz from the nearest per-revolution force (engine order).

2. If tested frequencies are substituted for calculated frequencies, frequencies tested at speed must provide a margin greater than 10 Hz from the nearest per-revolution forcing. Frequencies obtained in a spin-pit must be in accordance with the conditions of Section 1.8.4.

3. Identify in Table 1-14 all nodal diameter modes with a margin of 15 Hz or less. Also identify in Table 1-14 all nodal diameter modes within 5% of the nozzle passing frequency (NPF).

4. A detuned response analysis is required for any mode with a margin greater than 10 Hz but less than 15 Hz. A resonant response calculation is required for any mode that is within 5% of the NPF of the stage.

Table 1-13
Blade Disk Natural Frequencies (At Operating Speed)

	Stage Nozzle Passing Frequency?______________Hz			
	Frequencies Shown Are: _____Calculated _____Measured			
Nodal Diameter Number	**Mode A (Hz)**	**Mode B (Hz)**	**Mode C (Hz)**	**Mode D (Hz)**
Nodal Diameter # 0				
Nodal Diameter # 1				
Nodal Diameter # 2				
Nodal Diameter # 3				
Nodal Diameter # 4				
Nodal Diameter # 5				
Nodal Diameter # 6				
Nodal Diameter # 7				
Nodal Diameter # 8				
Nodal Diameter # 9				
Nodal Diameter # 10				

Table 1-14
Modes with Less Than 15 Hz Margin of Detuning from Resonance

ND Mode Family	ND# and Frequency	Nearest Engine Order	Margin
Mode __	ND#___at_____ Hz	__ per-rev @____Hz	Hz
Mode __	ND#___at_____ Hz	__ per-rev @____Hz	Hz
Mode __	ND#___at_____ Hz	__ per-rev @____Hz	Hz
Mode __	ND#___at_____ Hz	__ per-rev @____Hz	Hz
NPF	ND#___at_____ Hz	NPF @____Hz	Hz
	ND#___at_____ Hz	NPF @____Hz	Hz

1.7.3 General Requirement: Resonant Response Analysis

1. Provide a resonant response stress calculation for each of the first four nodal diameter mode families identified in Table 1-13 to identify the locations of maximum dynamic stress when the blade-disk modes encounter a resonant vibration condition.

2. Perform the resonant response stress calculation in accordance with Section 1.7.3.1.

3. Report in Table 1-15 maximum resonant stress at each structural feature of the blade-disk for nodal diameter mode families A through D.

4. Supply detailed contour plots as an addendum for each of the first four nodal diameter mode families that show the magnitude and distribution of resonant stress (ksi or MPa) in a single bucket under an assumed condition of resonance.

1.7.3.1 Subrequirement: Resonant Dynamic Stress Calculation

1. Estimate the resonant response (x) of a bucket by solving the differential equation shown in Equation 1-4.

$$M\ddot{x} + C\dot{x} + Kx = \underset{\rightarrow}{S} \cdot F_o \cdot e^{i(\omega t+\phi_j)} \qquad \textbf{Eq. 1-4}$$

   Where: M, C, and K are the mass matrix, damping matrix, and stiffness matrix respectively.
   S is the stimulus.
   F_0 is the steam bending force on the airfoil.
   e is the exponential base.
   i is an imaginary unit.
   ωt is the forcing frequency in radians per second.
   ϕ_j is the phase angle blade.

2. To calculate resonant response, assume a 10% stimulus (S) at NPF and at 1 per-revolution.

3. For low per-revolution forcing (2–10) of LP blades, assume a 3% stimulus. For low (2–10) per-revolution forcing of 1^{st} row HP, IP, and LP blades, assume a 4% stimulus. Assume a 1% stimulus for forces beyond the 10^{th} per-revolution.

4. Use a 0.15% critical damping ratio (ξ) for free standing blades and grouped blades. If the bladed disc has damping elements such as loose tie wire or "Z" cut shrouds, assume a 1.5% damping ratio.

Table 1-15
Resonant Dynamic Stress for the First Four Nodal Diameter Mode Families

Region	Mode A (Hz) ksi (MPa)	Mode B (Hz) ksi (MPa)	Mode C (Hz) ksi (MPa)	Mode D (Hz) ksi (MPa)
Cover: (Shroud/Integral)				
Tenon				
Tie Wire – Lashing Lug				
Airfoil – Leading Edge				
Airfoil – Trailing Edge				
Blade Root				
Disk Attachment				

1.7.4 General Requirement: Detuned Response Analysis

1. All modes with a margin from resonance greater than 10 Hz and less than 15 Hz should have operating dynamic stress estimated in a non-resonant (detuned) condition using Equation 1-5.

2. Report in Table 1-16 results for each mode along with the natural frequency of the mode, the nearest forcing frequency, and the forcing ratio.

1.7.4.1 Subrequirement: Detuned Dynamic Stress Calculation

1. In Equation 1-5, use a 0.15% critical damping ratio (ξ) for free standing blades and grouped blades.

2. If the bladed disc has damping elements such as loose tie wire or "Z" cut shrouds, assume a 1.5% damping ratio.

$$\sigma_d = \frac{2 \cdot \xi \cdot \sigma_R}{\sqrt{\left(1-\mu^2\right)^2 + \left(2 \cdot \mu \cdot \xi\right)^2}} \qquad \textbf{Eq. 1-5}$$

Where:
ξ is the critical damping ratio (c/c_c).
c is the damping coefficient.
c_c is the critical damping.
μ is the frequency ratio. $\mu = \omega / \omega_n$.
ω is the forcing frequency in radians per second.
ω_n is the natural frequency.
σ_R is the calculated resonant stress.

Table 1-16
Estimated Detuned Dynamic Stress for Each Mode

ND Mode*	Mode A (Hz)	Mode B (Hz)	Mode C (Hz)	Mode D (Hz)
Forcing Frequency (Hz)				
Natural Frequency (Hz)				
Frequency Ratio				
Dynamic Stress**	**Mode A (Hz) ksi (MPa)**	**Mode B (Hz) ksi (MPa)**	**Mode C (Hz) ksi (MPa)**	**Mode D (Hz) ksi (MPa)**
Cover: (Shroud/Integral)*				
Tenon*				
Tie Wire – Lashing Lug*				
Airfoil – Leading Edge				
Airfoil – Trailing Edge				
Blade Root				
Disk Attachment				
*Identified in Table 1-14 as having a margin of 15 Hz or less				
**Calculated using formulas from General Requirement 1.7.4				

1.7.5 Acceptance Criteria: Dynamic Stress/High Cycle Fatigue

1. All structural features should operate within a predicted dynamic stress (resonant or detuned) of less than 3 ksi (20.685 MPa) for any ND modes within the first four mode families identified in Table 1-16.

2. Calculate allowable dynamic stress (σ_a) using Equation 1-6.

$$\sigma_a = (\sigma_f - \sigma_o)(2\times 10^{10})^b \qquad \textbf{Eq. 1-6}$$

Where: σ_f and b are HCF growth parameters for the blade material reported in Table 1-17.
σ_o is the mean stress.

3. If the predicted dynamic stress for any structural feature exceeds 8 ksi (55.16 MPa), a design modification, supported by analysis, is required.

4. If the estimated resonant dynamic stress for any mode predicted within 5% of nozzle passing frequency is greater than 8 ksi (55.16 MPa), a design modification is required, supported by analysis, to demonstrate compliance.

5. If the dynamic stress is greater than 3 ksi (20.685 MPa) but less than 8 ksi (55.16 MPa), evaluate the rate of high cycle fatigue (HCF) damage for each mode of vibration and report it in Table 1-17. Perform the estimate of HCF damage in accordance with eq. 1-7, using the approach identified in Section 1.7.5.1.

6. The modified design should demonstrate that an HCF endurance limit exceeding 10^{10} cycles is achieved for the modes of concern.

1.7.5.1 Subrequirement: High Cycle Fatigue Damage

1. Base predicted HCF damage for each mode on the calculated dynamic stress amplitude *(σ_d)* and a stress versus number-of-cycles-to-failure (S-N) curve for the blade material.

2. Estimate crack initiation life (N_f) due to HCF based on the dynamic stress (σ_d) and the mean stress (σ_o) using Equation 1-7:

$$N_f = \frac{1}{2}\left(\frac{\sigma_d}{\sigma_f - \sigma_o}\right)^{1/b} \qquad \textbf{Eq. 1-7}$$

Where: σ_d is the dynamic stress.
σ_o is the mean stress.
σ_f and b are HCF growth parameters for the blade material reported in Table 1-17.

3. If a mode identified in Table 1-13 is within 10 Hz of the nearest per-revolution force, use the resonant dynamic stress in eq. 1-7.

4. If the margin is greater than 10 Hz, use the detuned dynamic stress amplitude in eq. 1-6.

5. Attach the S-N curve used to represent the blade material as an addendum.

6. Account for the effect of mean stress *(σ_o)* on HCF life in the prediction of HCF damage, where mean stress is based on the true stress and should also account for residual stress *(σ_r)*.

7. Report results in Table 1-17 as estimated cycles to crack initiation.

Table 1-17
Estimated HCF Initiation Life for Modes < 10 Hz Margin From Resonance

Dynamic Stress For Each Mode	Mode @ ___ (Hz)*	Mode @ ___ (Hz)*	Mode @ ___ (Hz)*
	Cycles to Crack Initiation by High Cycle Fatigue**		
Cover: (Shroud/Integral)*	cycles	cycles	cycles
Tenon*	cycles	cycles	cycles
Tie Wire – Lashing Lug*	cycles	cycles	cycles
Airfoil – Leading Edge	cycles	cycles	cycles
Airfoil – Trailing Edge	cycles	cycles	cycles
Blade Root	cycles	cycles	cycles
Disk Attachment	cycles	cycles	cycles
True Fracture Strength (σ_f) Applied:			
Fatigue Strength Exponent (b) Applied:			
* Identified in Table 1-13 as having a margin of 15 Hz or less			
**Calculated using Equation 1-7			

1.7.6 Acceptance Criteria: Low Cycle Fatigue - High Cycle Fatigue Interaction

1. Consider as acceptable all blades with a predicted LCF life of greater than 15,000 start-stop cycles and predicted operating stress of less than 3 ksi (20.685 MPa).

2. For blades operated in base load units, any structural feature that fails to achieve a predicted LCF of greater than 300 but less than 500 start-stop cycles is further required to demonstrate that the calculated dynamic stress for any given mode remains lower than 3 ksi (20.685 MPa). If the dynamic stress exceeds 3 ksi (20.685 MPa), a modification is required.

3. For blades to be installed on units that experience 100 or more start-stop cycles per year, any structural feature that fails to achieve a predicted LCF life of 15,000 cycles must demonstrate that the predicted operating dynamic stress remains lower than 3 ksi (20.685 MPa) for any given mode. If the dynamic stress exceeds 3 ksi (20.685 MPa), a modification is required.

4. If the number of allowable start-stop (N_f) cycles and respective dynamic stress fails to achieve the aforementioned limits, a design modification is required, supported with an FE analysis to demonstrate compliance.

1.7.7 Acceptance Criteria: Stress Corrosion Cracking - High Cycle Fatigue Interaction

1. For any components operated beyond the Wilson line (that is, "wet" stages) where the steady stress is greater than 50% yield strength, a calculation is required to demonstrate that the operating dynamic stress does not exceed 3 ksi (20.685 MPa).

2. If the operating dynamic stress is higher than 3 ksi (20.685 MPa), a design modification is required, supported by analysis to demonstrate compliance.

1.7.8 Acceptance Criteria: Creep - High Cycle Fatigue Interaction

1. For any stages operated at 850°F (454.4°C) or higher where the creep strain is greater than 0.5%, a calculation is required to demonstrate that the operating dynamic stress does not exceed 3 ksi (20.685 MPa).

2. If the operating dynamic stress is higher than 3 ksi (20.685 MPa), a design modification is required, supported by analysis to demonstrate compliance.

1.7.9 General Requirement: High Cycle Fatigue in Heat-Affected Zone

1. Identify any structural feature of the bucket that requires welding and/or results in a heat-affected zone (HAZ). If the HAZ is left untreated, a calculation is required to demonstrate that the operating dynamic stress in the zone does not exceed 3 ksi (20.685 MPa).

2. If the operating dynamic stress is higher than 3 ksi (20.685 MPa), a design modification is required, supported by analysis to demonstrate compliance.

1.8 Quality Control Measures

1.8.1 General Requirement: Pre-Installation Frequency Testing

1. As an initial check of the dynamic properties of the buckets, perform frequency tests first for individual components prior to acceptance and installation on the turbine.

2. Before delivery of the buckets, provide the *target frequencies* expected for each of the first three modes of a single blade when mounted in a fixture and frequency tested. Provide the target frequencies and test results in the format shown in Table 1-18.

3. The acceptance criteria for individual blades tested in a fixture is required to come within 2% of the target frequencies identified for the first two modes. For the third mode, a difference of less than 5% is allowed.

4. The test rig should use a fixture that conforms to the original root, where the blade/bucket root can be pressed against the attachment to simulate a condition of normal centrifugal lock-up of the attachment.

5. Excite the blade using an instrumented hammer within a range sufficient to identify and document the frequencies of the first four modes for each blade.

6. Indicate the delivery of the frequency check results on any milestone schedule supplied in response to this procedure.

Table 1-18
Record of Frequency Tests for Individual Blades

	Mode 1	Mode 2	Mode 3	Mode 4
Target (± 2%)	Hz	Hz	Hz	Hz
Measured Blade #1	Hz	Hz	Hz	Hz
Measured Blade #2	Hz	Hz	Hz	Hz
Measured Blade #3	Hz	Hz	Hz	Hz
Measured Blade #N	Hz	Hz	Hz	Hz

1.8.2 General Requirement: Assembly Tolerances

1. For blades that rely on tangential entry root designs, the purchaser should check the tolerances of any accessible root load-bearing surfaces and compare them against the values specified in Section 1.3.1 before installation of the components in the turbine.

2. The allowable tolerance for a root attachment is specified at 0.005" (0.127 mm) for any given load-bearing surface.

3. To check the quality of root tolerances, take coordinate measurements at no fewer than five points per load-bearing surface.

4. Identify alternative root tolerance limits in advance.

5. For integral cover bucket designs in which a continuous linking is to be achieved by untwisting of the bucket under centrifugal force, identify the minimum and maximum allowable gaps at zero rpm before installation.

6. By means of analysis, demonstrate that at the minimum allowable gap size, centrifugal stresses in the covers between adjacent blades do not exceed 50% of material yield strength at full speed operation.

7. By analysis, demonstrate that for the maximum allowable gap size at zero rpm, centrifugal force will close the gaps at 80% of rotating speed.

1.8.3 General Requirement: Blade - Disk Frequency Testing at 0 rpm

1. Before delivery of the buckets, provide the target frequencies expected for each of the first three modes when mounted on a disk as an assembled row. As a final check of the assembled row, perform a modal frequency test after the installation of buckets is completed.

2. The measured frequencies should be within 2% of the target frequencies for the first two modes. For the third mode, a difference of less than 5% is allowed. If the root is loose, apply Locktite before the test. Submit results of the tests in the format shown in Table 1-19.

3. If the frequencies of the blade or blade group measured on the disk are 90% or less of the predicted zero-rpm frequencies, replace the blade or group.

Table 1-19
Record of Frequency Tests for Installed Blades/Blade Groups

	Mode 1	Mode 2	Mode 3	Mode 4
Target (± 2%)	Hz	Hz	Hz	Hz
Measured Blade #1	Hz	Hz	Hz	Hz
Measured Blade #2	Hz	Hz	Hz	Hz
Measured Blade #3	Hz	Hz	Hz	Hz
Measured Blade #N	Hz	Hz	Hz	Hz

1.8.4 General Requirement: Blade - Disk Frequency Testing

1. Perform telemetry testing to obtain frequency data for the two fundamental mode frequencies. Results should clearly show the frequencies near the rotor operating speed.

2. A minimum of six telemetry channels are required to test any row of blades in a vacuum chamber. Place two gauges above the platform on the trailing edge of the blade suction side. Place two gauges above any tie wire or connecting device. Place two thermocouples on the airfoil, one near the tip and one near the platform.

3. Record the frequency and thermocouple data during ramp-up and ramp-down by using a DC exciter. Provide a waterfall diagram for both ramp-up and down to display the frequency changes with rotor speed.

4. Determine the natural frequencies of the blade-disk under actual operating conditions by compensating for both the rotor speed and temperature of the simulated (spin-pit) test.

1.9 Nomenclature

The following table identifies nomenclature used within this procedure.

Table 1-20
Terminology Alternatives for Turbine Components [2]

Rotating Blades and Parts	Alternative Terms
Rotating blades	Buckets
Blade root	Serrations, attachments, fir trees, hooks, attachment base
Blade shank	Blade tail
Blade base	Platform
Blade airfoil	Vane, partition, foil
Pin and finger root	Pinned finger, fork-shaped fastening
Fir-tree (attachment)	Dovetail
Pins	Prongs
Tie wires	Lacing wires, lashing wires, arch bands, snubber, connectors
Shrouds	Covers, bands, cover bands, integral shrouds, spill strips
Tuned blade packets	Harmonic shrouding
Tenons	Rivets, pegs
Tenon rivet	Tenon upset, tenon head
Countersunk tenon rivet	Foxholed tenon
Dovetail	Steeple, roots and grooves
Blade group	Blade packet
Closing blade	Notch piece / blade
Stationary Blades and Parts	**Alternative Terms**
Stationary blades	Nozzles
Nozzle chests	Nozzle boxes, nozzle plate, nozzle chamber/block
Diaphragms	Partitions, blade ring/carrier, stationaries, rings
Stationary vanes	Nozzle foils, nozzle vanes, nozzle partitions
Other Components	**Alternative Terms**
Inlet	Bowl
Control stage	First stage, governing stage, partial admission stage, inlet stage.
Rotor	Shaft, wheel, spindles
Disc	Wheel
Keyways of discs	Anti-rotation pin slots
Disc-rim blade attachment	Steeple
Blade entry slot	Gate, notch
Seal	Sealing labyrinth, labyrinth seal, sealing fin, packing ring, packing, gland, sealing strip, spill strip
Turning gear	Barring gear
Pedestal	Standard
Turbine Section	Cylinder
Exhaust hood	Exhaust port
Turbine casing	Shell, cylinder
Sleeve rings	Snout rings, piston rings, inlet rings
Attemperators	Sprays

1.10 Materials and Properties

Tables 1-21 through 1-26 present details of material and mechanical properties on buckets and rotors. These details are drawn from the EPRI report *Turbine Steam Path Damage: Theory and Practice (Volumes 1 and 2)* [2, 3]. They are provided as further reference for comparing and contrasting the information requested in Tables 1-2 through 1-8 of this procurement procedure.

Table 1-21
Composition of Materials Commonly Used for LP Blades [2]

Element	12% Cr Stainless Steels				Titanium
AISI Type or European Designation	**AISI 403 (Generic)**	**AISI 410 (Generic)**	**X20CrMoV121 (Example)**	**X20Cr13 (Example)**	
Carbon	0.15±0.005	0.15±0.005	0.22	0.19	0.020–0.040
Manganese	1.00±0.030	1.00±0.030	0.40	0.53	
Phosphorus	0.04±0.005	0.04±0.005	0.017	0.017	
Sulfur	0.03±0.005	0.03±0.005	0.004	0.013	
Silicon	0.50±0.050	1.00±0.050	0.38	.024	
Chromium	11.5–13.0 ±0.150	11.5–13.0 ±0.150	12.4	13.3	
Molybdenum			0.49	0.03	
Nickel	0.60±0.030		0.96	0.43	
Tungsten					
Vanadium			0.28		4.1–4.5
Nitrogen				0.04	0.010–0.019
Copper				0.06	
Aluminum					6.2–6.6
Oxygen					0.12–0.20
Hydrogen					0.002–0.006
Iron					0.100–0.008
Titanium					Balance

Table 1-21 (continued)
Composition of Materials Commonly Used for LP Blades [2]

Element	Precipitation-Hardened Materials			Duplex Steels	
	17-4 PH	15-5 PH	13-8 PH	Ferralium 255	
AISI Type or European Designation	AISI 630	X5CrNiMoCu145 (Example)	X3CrNiMoAl1382 (Example)	AISI	X3CrMnNiMoN 2264 (A905) (Example)
Carbon	0.07 max	0.04	0.03	0.04 max	0.02
Manganese	1.00 max	0.42	0.03	0.80	5.6
Phosphorus	0.03 max	0.024	0.004		0.007
Sulfur	0.03 max	0.010	0.003		0.002
Silicon	1.00 max	0.42	0.04	0.45	0.38
Chromium	15–17.5	14.5	12.7	26	25.8
Molybdenum	0.50 max	1.75	2.22	3.0	2.1
Nickel	3–5	4.83	8.47	5.5	3.8
Niobium		0.32			
Tungsten					
Vanadium					
Columbium					
Columbium + Tantalum	0.15–0.45 (or as 5X C; 0.45 max)				
Copper	3–5	1.52	0.01	1.7	
Aluminum			1.04		
Oxygen					
Hydrogen					
Nitrogen				0.17	0.33
Iron					
Titanium					

Table 1-22
Mechanical Properties of Materials Used for LP Turbine Blades [2]

Property	**AISI Type 403/410 (Generic)**	**Precipitation Hardened 17-4 PH**	**Titanium (TI-6Al-4V)**	**Duplex Stainless Steel (Ferralium 255)**
Condition	Hardened and tempered at 648°C(1200°F)	Hardening temperature = 496°C (925°F)	Annealed	Plate, heat treated at 1120°C (2050°F), rapidly cooled
Specific Weight kg/m^3(lb/in^3)	7750 (0.28)	7750 (0.28)	4430 (0.16)	7806 (0.282)
Modulus of Elasticity, GPa (10^6 psi)	200 (29)	195 (28.5)	114 (16.5)	210 (30.5)
Tensile Strength MPa (ksi)	760 (110)		950 (138)	867 (125.8)
0.2% Yield Strength MPa (ksi)	585 (85)	1070 (155)	88 (128)	674 (97.8)
Elongation (%)	23	10	13	27
Reduction in Area (%)	60	41		
Brinell Hardness	225	375-438		
Endurance Limit MPa (ksi)	275 (40)	550 (80)	520 (75)	

Note: The mechanical properties for these materials are very dependent on manufacturing process, tempering temperature, and composition. The values are "typical" for the alloy and heat treatment shown. Use application-specific, as-measured properties for any analysis of blading.

Table 1-23
Composition and Properties of Materials Used for HP Turbine Blades [2]

Element	Martensitic Stainless Steel AISI Type 422 (Generic)	Austenitic Stainless Steel (Bohler Turbotherm 17 13 W)
Carbon	0.22±0.020	0.10
Manganese	0.69±0.030	
Phosphorus	0.02±0.005	0.03
Sulfur	0.03±0.005	0.003
Silicon	0.50±0.050	1.00
Chromium	11.5–12.5 ± 0.150	16.0
Molybdenum	0.93±0.050	
Nickel	0.76±0.030	13.5
Tungsten	0.97±0.050	2.80
Vanadium	0.21±0.050	
Thallium		0.50
Property	**Martensitic Stainless Steel AISI Type 422 (Generic)**	**Austenitic Stainless Steel (Bohler Turbotherm 17 13 W)**
Tensile Strength MPa (ksi)	967 (140)	538–732 (78–106) Quenched 635–830 (92–120) Hot & cold formed
0.2% Yield Strength MPa (ksi)	795 (115)	248 (36) Quenched 442 (64) Hot & cold formed
Elongation (%)	13	30% Quenched 25% Hot & cold formed
Reduction of Area (%)	25	
Brinell Hardness	293–341	
Charpy V-Notch Impact at Room Temperature m-kg (ft-lb)	2.14–2.34 (15.5–17)	

Table 1-24
Materials Commonly Used in the Construction of Rotors [2]

Component	Generic Name	ASTM Alloy Designation
LP Rotor	2.0 NiMoV	A293, Classes 2 & 3
	2.5 NiMoV	A293, Classes 4 & 5
	2.5 NiMoV	A470, Classes 2 & 3
	3.5 NiCrMoV	A470, classes 5 to 7
	20 Mn 5	None, (DIN, Wks, 1.1133)
	24 Ni 4	None, (DIN, Wks, 1.5613)
	24 Ni 12	None
	22 NiCrMoV 12	None
LP Disc	2.8 NiMoV	A294, Grades B & C
	3.5 NiCrMoV	A471, Classes 1 to 3
HP Rotor	1 CrMoV	A293, Class 6
	1 CrMoV	A470, Class 8
	12 CrMoV	A565, Gr. 616
	12 CrMoV	A768, Class 1
	-20 CrMoV 12 1	None (DIN, 1.4922)
	-22 CrMoWV 12 1	None (DIN, 1.8212)
	30 NiCrMoV 5 11	None (DIN, Wks. 1.6946)
HP Disk	1 CrMoV	A471, Class 5 & 10
	26 NiCrMoV 11 5	None (DIN, Wks. 1.6948)

Table 1-25
Composition and Properties of Commonly Used Rotor and Disk Materials [2]

Property/Composition	LP Rotor 3.5 NiCrMoV (A470 Class 6)[1]	LP Disc 3.5 NiCrMoV (A471, Class 3)[2]	HP Rotor 12CrMoV (A565, Gr.616)[3] (Heat-treated)
Composition			
Carbon	0.28 max	0.28 max	0.20–0.25
Manganese	0.20–0.60 (0.40 max)[4]	0.70 max	0.5–1.0
Phosphorus	0.012 max	0.012 max	0.05 max
Sulfur	0.15–0.30[5] (0.10 max)[4]	0.15–0.35[5]	0.50 max
Nickel	3.25–4.00	2.0–4.0	0.5–1.0
Chromium	1.25–2.00	0.75–2.0	11.0–12.5
Molybdenum	0.25–0.60[6] (0.25–0.45)[4]	0.20–0.70	0.90–1.25
Vanadium	0.05–0.15	0.05 min	0.20–0.30
Antimony	Note 4 and 7	Note 7	
Tin	Note 4		
Tungsten			0.90–1.25
Mechanical Properties			
Tensile Strength, Min, MPa (ksi)	725-860 (105-125)	760 (110)	965 (140)
Yield Strength, Min, MPa (ksi), 0.2% offset	620 (90)	690-825[8] (100-120)[8]	760 (110)
Elongation in 50 mm or 2 in., Min., % *Longitudinal Prolongation *Radial Body	 18 17	18	13
Reduction in Area, Min., % *Longitudinal Prolongation *Radial Body	 52 50	47	30
FATT 50 max	-7°C (20°F)	-18°C (0°F)	
Room Temp. Impact, Min. J (ft. lb.)	61.2 (45)	61.2 (45)	11 (8)
Brinell Hardness			302-352

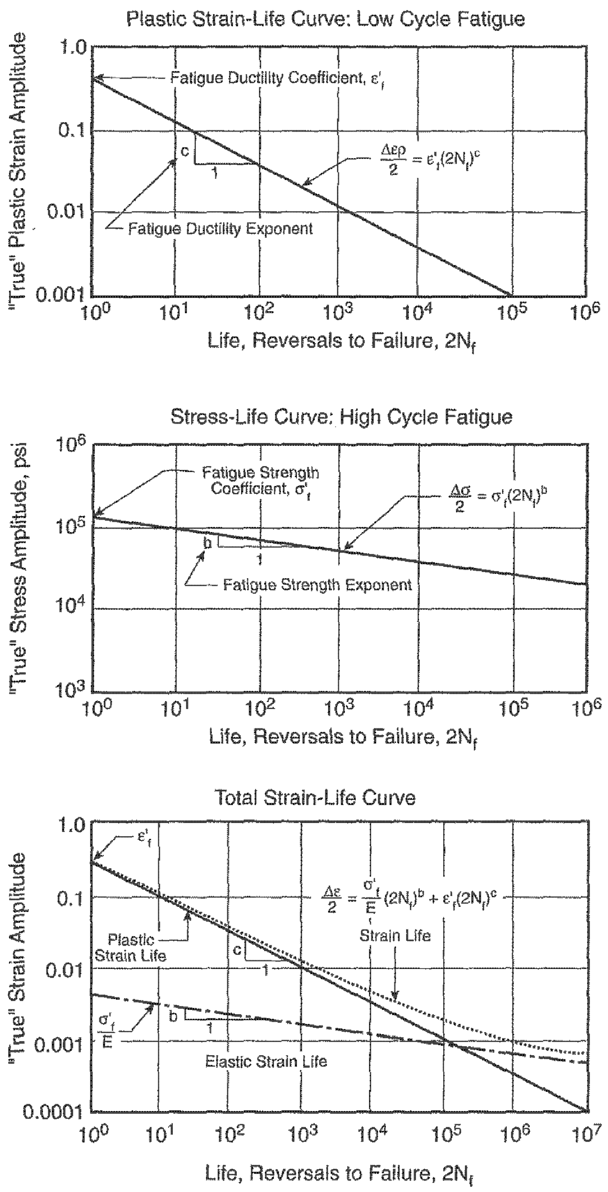
Notes:
1. ASTM A470, Standard Specification for Vacuum-Treated Carbon and Alloy Steel Forgings for Turbine Rotors and Shafts.
2. ASTM A471, Standard Specification for Vacuum-Treated Alloy Steel Forgings for Turbine Rotors, discs and wheels.
3. ASTM A565, Standard Specification for Martensitic Stainless Steel Bars, Forgings, and Forging Stock for High-Temperature Service.
4. Special Composition requirements to minimize temper embrittlement.
5. May be vacuum-carbon deoxidized, silicon, 0.10 max.
6. If required due to operating temperatures, 0.40 % Mo may be specified.
7. To be reported for information only.
8. 0.2% offset.

Table 1-26
Composition of Selected European Rotor Materials [2]

Rotor Material	Din Wks. No.	C	Si	Mn	P	S	Cr	Mo	Ni	V	W
20 Mn 5	1.1133	0.17–0.23	0.30–0.60	1.00–1.30	0.035	-	-	-	-	-	-
24 Ni 12	-	0.25 nom	-	0.90 nom	-	-	-	-	3.0 nom	-	-
22 NiCrMoV 12	-	0.25 nom	-	0.47 nom	-	-	1.50 – 2.00	0.40 – 0.60	2.80–3.20	0.11	-
26 NiCrMo 11 5	1.2726	0.22–0.30	0.30–0.50	0.20–0.40	0.03	0.03	0.60 – 0.90	0.20 – 0.40	1.30–1.60	0.15	0.20
X20 CrMoV 12 1	1.4922	0.17–0.23	0.50	1.00	0.030	0.030	10.0 – 12.5	0.80 – 1.20	0.30–0.80	0.25–0.35	-
X21 CrMoWV 12 1	1.4926	0.20–0.26	0.50	0.30–0.80	0.25	0.20	11.0 – 12.5	0.80 – 1.20	0.30–0.80	0.25–0.35	0.30
24 Ni 4	1.5613	0.20–0.28	0.15–0.35	0.60–0.80	0.035	0.035	0.30	-	1.00–1.30	-	-
24 Ni 8	1.5633	0.20–0.28	0.15–0.35	0.60–0.80	0.035	0.035	0.30	-	1.90–2.20	-	-
30 NiCrMoV 5 11	1.6946	0.28–0.32	0.30	0.15–0.40	0.015	0.018	1.20 – 1.80	0.25 – 0.45	2.4–3.1	0.05–0.15	-
26 NiCrMoV 14 5	1.6957	0.22–0.32	0.30	0.15–0.40	0.015	0.018	1.20 – 1.80	0.25 – 0.445	3.4–4.0	0.05–0.15	-
21 CrMoV 5 11	1.8070	0.17–0.25	0.30–0.60	0.30–0.60	0.035	0.035	1.20 – 1.50	1.00 – 1.20	0.60	0.25–0.35	-

1.11 Stress and Fatigue Life

Figure 1-4 provides additional detail on the relationship of relevant terms used in Sections 1.7.5 and 1.7.6 to estimate crack initiation life. Table 1-27 presents details of cyclic properties drawn from the EPRI report *Turbine Steam Path Damage: Theory and Practice (Volumes 1 and 2)* [2, 3]. They are provided as further reference for comparing and contrasting the information requested in Tables 1-5 and 1-6 of this procurement procedure.



Montonic Properties

- Elastic Modulus .... E
- Yield Strength .... Sy
- Tensile Strength .... UTS
- Reduction in Area .... %RA
- True Fracture Strength .... σ_f
- True Fracture Ductility .... ε_f
- Hardening Coefficient .... K
- Strain Hardening Exponent .... n

Cyclic Properties

- Fatigue Strength Coefficient .... σ'_f
- Fatigue Strength Exponent .... b
- Fatigue Ductility Coefficient .... ε'_f
- Fatigue Ductility Exponent c
- Cyclic Hardening Coefficient .... K'
- Cyclic Strain Hardening Exp. .... n'

1 psi = 0.0069 MPa

Figure 1-4
Definition and Formulation of Stress and Fatigue Life Curves [4]

Table 1-27
Cyclic Fatigue Properties for 12% Cr Stainless Steel [3]

Material	Fatigue Strength Coefficient, σ_f' (MPa)	Cyclic Strain Hardening Coefficient, n'	Notes
Type 403	962	0.110	High strain rates
Type 403	932	0.128	Lower strain rates
Type 403	1172	0.125	
Type 410	1472	0.143	For $\Delta\varepsilon_p < 1\%$
Type 410	1472	0.218	For $\Delta\varepsilon_p > 1\%$
Type 422	1216	0.093	Higher strain rates
Type 422	1249	0.099	Lower strain rates

Dave

4 DESIGN AUDIT AND INSPECTION FOR A CONTROL STAGE BLADE FROM A GE G3 UNIT WITH A 30-INCH (76-CM) LSB

4.1 Basic Elements of This Document

A design audit includes two basic rules that are commonly practiced by all manufacturers:

- Blade centrifugal stress is minimized during operation.
- Fundamental modes and frequencies of longer blades (>12" or >30.48 cm) are sufficiently tuned to avoid coinciding with the first 10 engine orders of rotating speed.

The flow chart in Figure 4-1 offers a systematic method for obtaining key information and criteria that could be used to establish the inherent strengths or weaknesses of any particular bucket or blade. Note to the maintenance engineer: **It is unlikely that a majority of turbine blades presently in service have been put through such a rigorous design evaluation**, despite the fact that finite element (FE) analysis has been commercially available for over 20 years. **It should also not be assumed** that even the most critically loaded high-pressure (HP) control stage, first reheat stage, and last two to three low-pressure (LP) turbine rows have been scrutinized in such detail.

In general, the approach used to evaluate blades is based on three fundamental assumptions:

- Steady stress of sufficient magnitude to initiate cracks resulting from low cycle fatigue (LCF) tends to be concentrated and localized. If the calculated steady stress is predicted to exceed the yield strength of the material, the true stress-strain must be accounted for to determine how many start-stop cycles could be experienced before cracks might initiate from LCF.
- If the blade-disk frequencies are properly detuned from the lower order per revolution (per-rev) forces, dynamic stress will be nominal, and any high-cycle fatigue (HCF) will be inconsequential over the life of the blades.
- Once cracks are initiated in a blade-disk, the original inherent reliability designed by the OEM has been compromised. The risk of continued operation is dependent, in part, upon the degree of conservatism available within the design to allow cracks to be removed or tolerated for limited periods of continued operation.

As shown in Figure 4-1, the analysis is divided into two basic calculations: steady and dynamic. As the criteria suggest, if stresses are nominal, further steps of the examination are not necessary to qualify a new design as acceptable. For certain thresholds, additional effort is prescribed to

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more precisely quantify these stresses, for example, calculation of true stress-strain, blade-disk resonant response, and/or detuned response.

For maintenance and inspection purposes, crack initiation and crack propagation estimates based on these stresses are carried to their logical conclusion. This is done to provide the operator with additional insight on how much conservatism may exist within the component when faced with making decisions based on inspection data, particularly for blades that have been in use for some time.

These estimates are not meant to be absolute predictions of remaining life. The estimates represent another perspective to judge a design's sensitivity to damage that may be accumulated over time. To assess conditions such as solid particle erosion (SPE) or stress corrosion cracking (SCC), the original stress results are treated probabilistically.

The following information reports the results of this systematic examination of a control stage blade. The results are summarized as a series of tables for further use in the procurement, inspection, or repair of these blades.

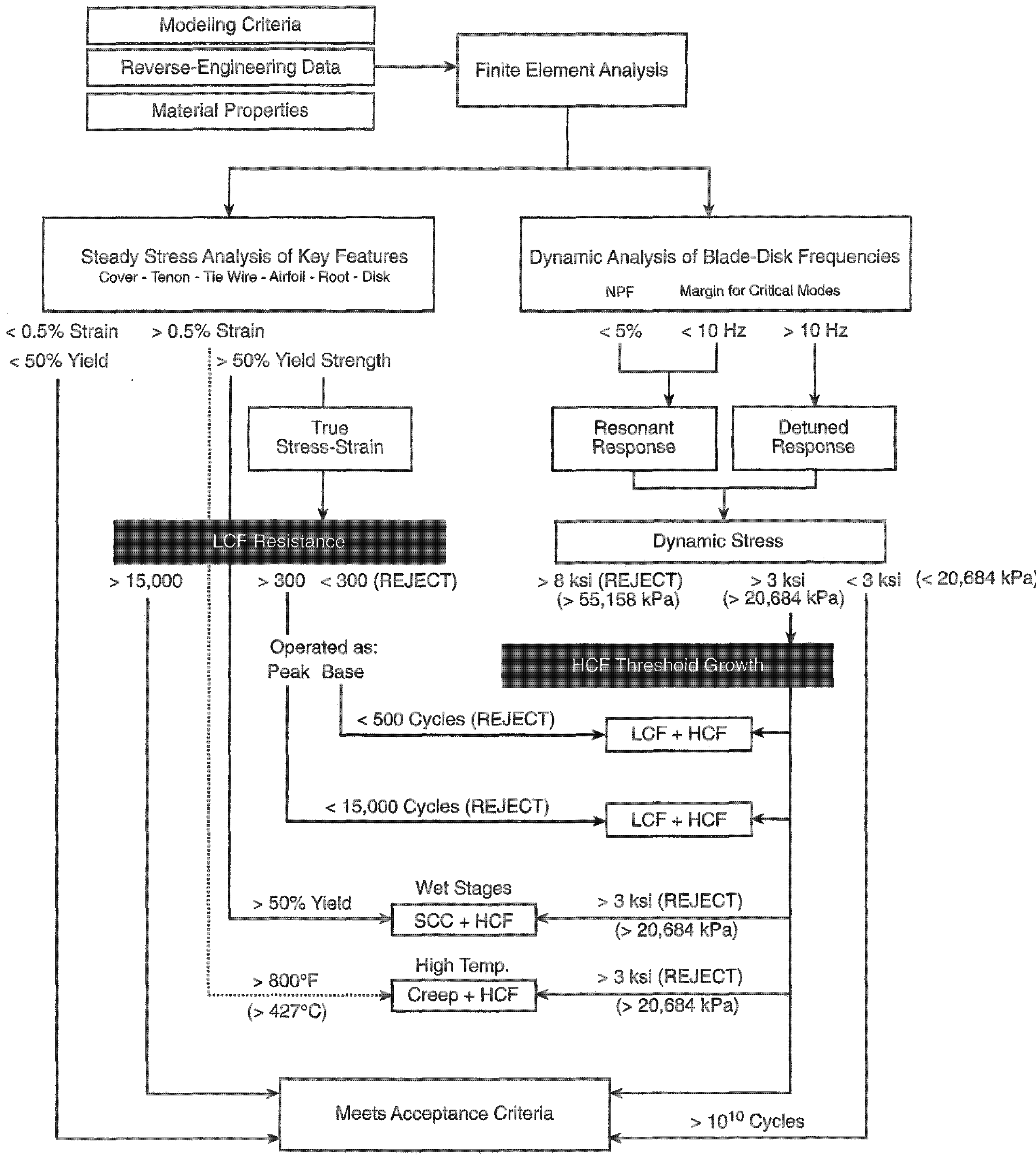

Figure 4-1
Design Audit Procedure and Assessment Criteria

4.2 Applications for Results

4.2.1 Recommended Applications

To apply the stress results or fatigue life predictions presented in these guidelines, the maintenance engineer must recognize the stage of the maintenance sequence that is being supported:

- For planning and pre-bidding, the stress, frequency, and crack initiation predictions provide input to the generic blade procurement specification.
- While inspecting the turbine, locations of maximum steady stress and predictions of crack initiation life are provided to indicate regions of the blade root that are more susceptible to LCF, SCC, or creep. Locations of maximum dynamic stress for each different mode of vibration indicate regions more susceptible to HCF and more sensitive to any deterioration or damage accrued over time.
- To assess the condition of LP blades against crack initiation from resonant vibration of the fundamental modes, an interference diagram is provided in Figure 4-10. The diagram illustrates a way to check or monitor the dynamic properties of a blade-disk by modal testing.
- To guide the application of preventive or minor repair measures (grinding or polishing) of surface damage to the airfoil, estimates of damage tolerance limits are provided based on a comparison of estimated dynamic stress to the threshold stress intensity factor of the material.
- To make run-repair-replacement decisions where significant damage resulting from SPE is identified. Probability of failure curves for various levels of corrosion damage are presented to aid the operator in determining the level of risk associated with the recorded SCC data from a specific unit.

4.2.2 Relationship of Damage Mechanisms in Blades

Rotating components of a turbine are distinctive because they are subject to a minimum of two or three different stresses (centrifugal, vibratory, and thermal stress) simultaneously during normal operation. The sequence leading to failure can involve one or more of these sources of fatigue at any given time. Avoiding an in-service failure for these components is always the essential issue in any determination of run-replace-repair.

The relationship of this sequence to common sources of damage or degradation is shown in Figure 4-2. Typically, if resonance is avoided, crack initiation is dominated by LCF and/or SCC for "wet" stages or SPE for the first HP and intermediate-pressure (IP) stages. If a crack is formed, these mechanisms will continue to dominate the propagation process until the initial crack reaches a certain length where dynamic stress at the crack front exceeds the threshold stress intensity of the material. At this point, rapid crack propagation will result.

Since all operating blades vibrate, the last mechanism typically involved before rupture is HCF. (This statement presumes that a well-designed blade does not experience dynamic stress on an order of magnitude sufficient to initiate cracks as a result of HCF.) Because blades vibrate at such high frequencies, the remaining life of the blade is reduced to days or weeks after this threshold is exceeded. Long-term reliability is best measured as the time/cycles for initiation to occur, with the presumption that original frequency margins are maintained.

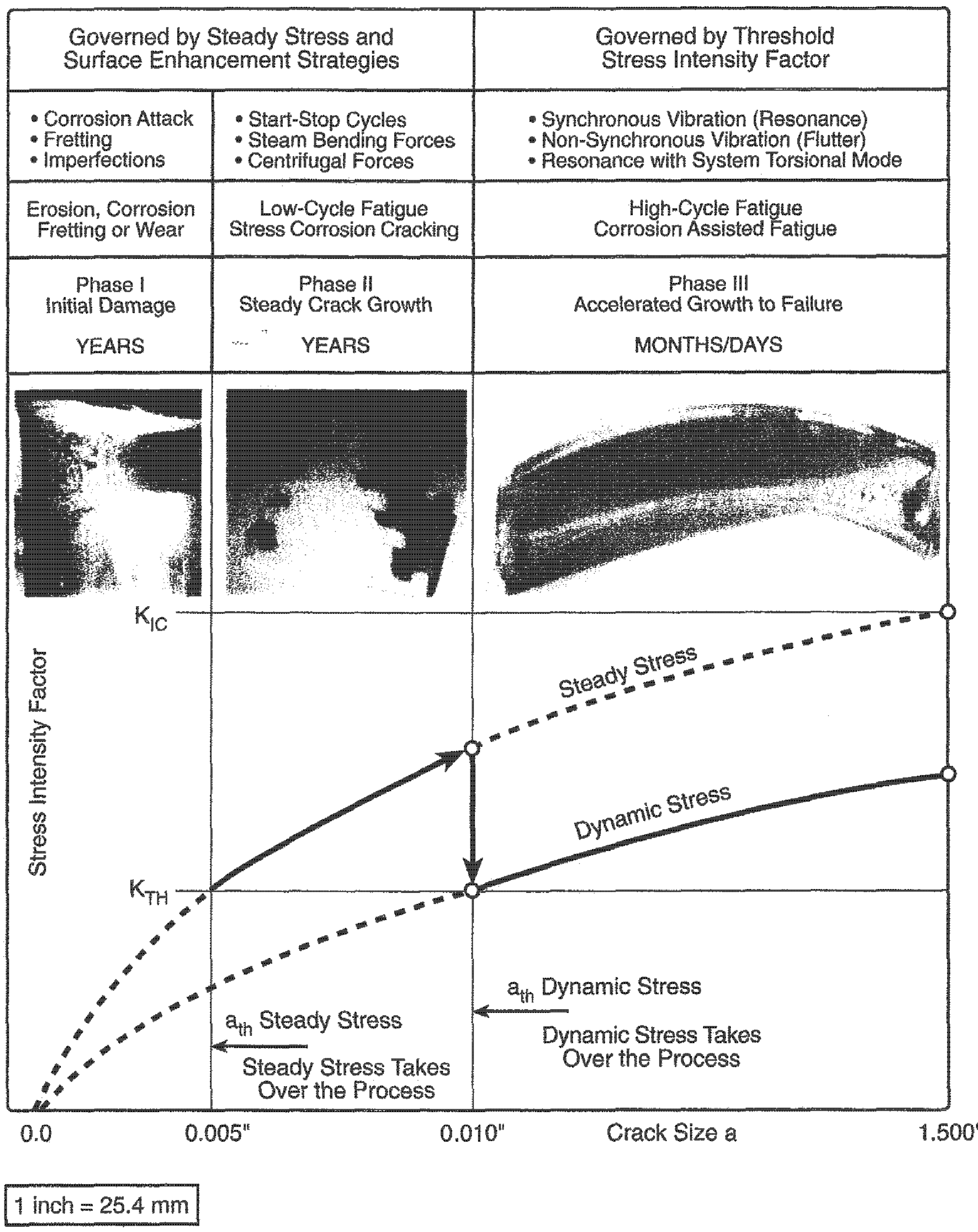

Figure 4-2
Sequence of Crack Development and Growth Process

The current U.S. fleet of turbines now comprises many vintage units. Turbine rows that started service in pristine condition have been subjected to years of normal wear, erosion, and degradation. The critical path of a maintenance schedule may not allow for delays to immediately replace a row of damaged blades. Therefore, this document extends the basic information on stress to provide estimates of damage resistance or the maximum damage that the blade might tolerate at each of the most critically stressed locations. However, these estimates should be used only as general guidance for determining whether grinding, polishing, or limited service are viable options. Actual dynamic stress levels for an individual row can only be approximated and not calculated exactly. A margin of safety should always be applied to any estimates of remaining life involving either crack initiation or propagation. Where uncertainty exists as to whether cracks have been completely removed, the risk of failure is weighed as a probability.

Under LCF, crack growth is stable and predictable and, therefore, can be related to the stress calculated from the FE analysis and the number of start-up and shut-down cycles of the unit. This guideline approaches the inherent resistance of the blade to LCF by assuming that a measurable indication of 30 mils (0.762 mm) (representing a potential crack) exists in a selected region of maximum steady stress. The crack growth rate is also used in conjunction with the results from the steady stress analysis to estimate the growth rate of the crack under continued start-stop operation without the influence of any other unusual or abnormal loads or forces.

When a crack starts to propagate under the influence of HCF, the remaining life of the blade is essentially compromised. To further judge the sensitivity of regions in the blade to the presence of a crack and assess the risk of an in-service failure, the dynamic stress is contrasted against the stress intensity factor. Taken in conjunction with an estimate of the crack length at the threshold where HCF would take control, the results provide an indication of how much further damage might be sustained. SPE is evaluated in terms of when an HCF failure is predicted.

Because of random differences introduced during the manufacture, fabrication, and installation of blades, estimates of crack initiation life should always be viewed as having the potential to be plus or minus an order of magnitude different and not as exact predictions of when cracks will or must appear. As previously stated, if cracks have been initiated by HCF, this indicates that sufficient dynamic forcing is present to finish what was started. Tolerance assumes that levels of dynamic stress are insufficient to initiate cracks without the presence of an existing stress singularity. Conversely, cracks appearing in locations other than those dictated by the predicted maximum steady or dynamic stress suggests the presence of an abnormal load condition that the blade may not be designed for or equipped to handle.

4.3 Features of the Blade and FE Model

4.3.1 Design Features

A photograph of the blade examined in this document is shown in Figure 4-3.

In the G3 HP turbine, 72 blades are inserted around the circumference of the disk. The cover consists of a pair of integrally forged tenons located in parallel to each other. The tenon stubs protrude through a shroud piece and are peened to rivet the shroud into place. This forms an arrangement of four blades per group for a total of 18 groups. The short airfoil is derived from a straight impulse-type profile. The root is a tangential entry-type of straddle-mount root with six load-bearing surfaces (three pairs of hooks). The blade is machined from AISI 422 stainless material.

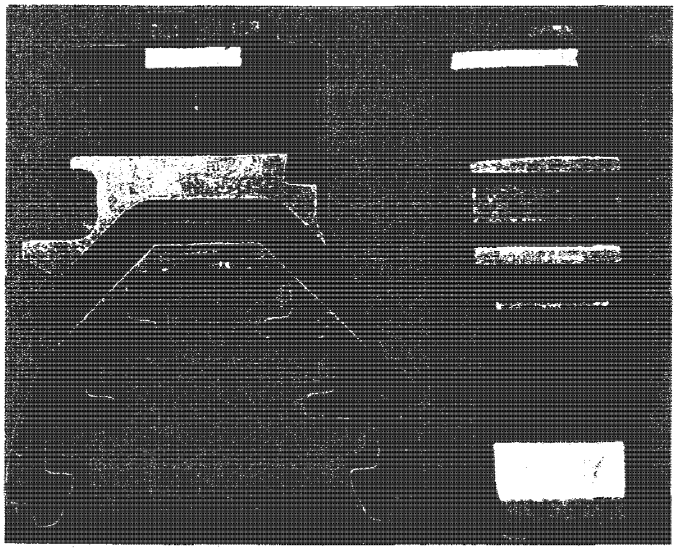

Figure 4-3
Typical Control Stage Blade

4.3.2 Statistics

The control stage blade examined in this study is associated with a G3 unit configuration that operates with a last-stage blade of 30" (762 mm). Table 4-1 summarizes the information contained in Volume 5 of this *Guidelines for Reducing the Time and Cost of Turbine-Generator Maintenance Overhauls and Inspections* series. Units with different configuration that also operate with the same last-stage blade length are summarized. The first G3 machine was put into operation around 1973. The blade on which this analysis is based was put into service in 1974. In the United States today, there are 12 of these units in operation, with an average nameplate capacity of 788 MWe. A detailed list of these turbines can be found in Table 4-3 of Volume 5. **Note:** Information related to the current status and ownership of these units is subject to change.

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Table 4-1
G3 Units in the United States (Includes Other GE Turbines with 30" (76-cm) LSBs)

Designation	Number of Units	Retired/Standby	Rating (MWe)	In Service
D5	2	-	290	1968–1972
D6	18	-	194–315	1962–1980
D8	16	-	305–365	1967–1982
G2	30	-	351–668	1967–1982
G3	30	1	576–799	1967–1991
G3D	6	-	782–806	1968–1975
G7	5	-	605–659	1974–1985
S1	3	-	613–615	1967–1968
S2	6	-	820–914	1975–1987

4.3.3 Finite Element Analysis Model

The images in Figure 4-4 represent different features of the blade that were included in the FE model (FEM):

- Part A shows the entire model without the disk.
- Part B shows details of the cover that is used to join adjacent blades.
- Part C shows the airfoil of a single blade from platform to tip.
- Part D shows details of the root.

Details of the model were defined from dimensions that were reverse-engineered from a sample blade specifically for the purpose of performing a structural analysis.

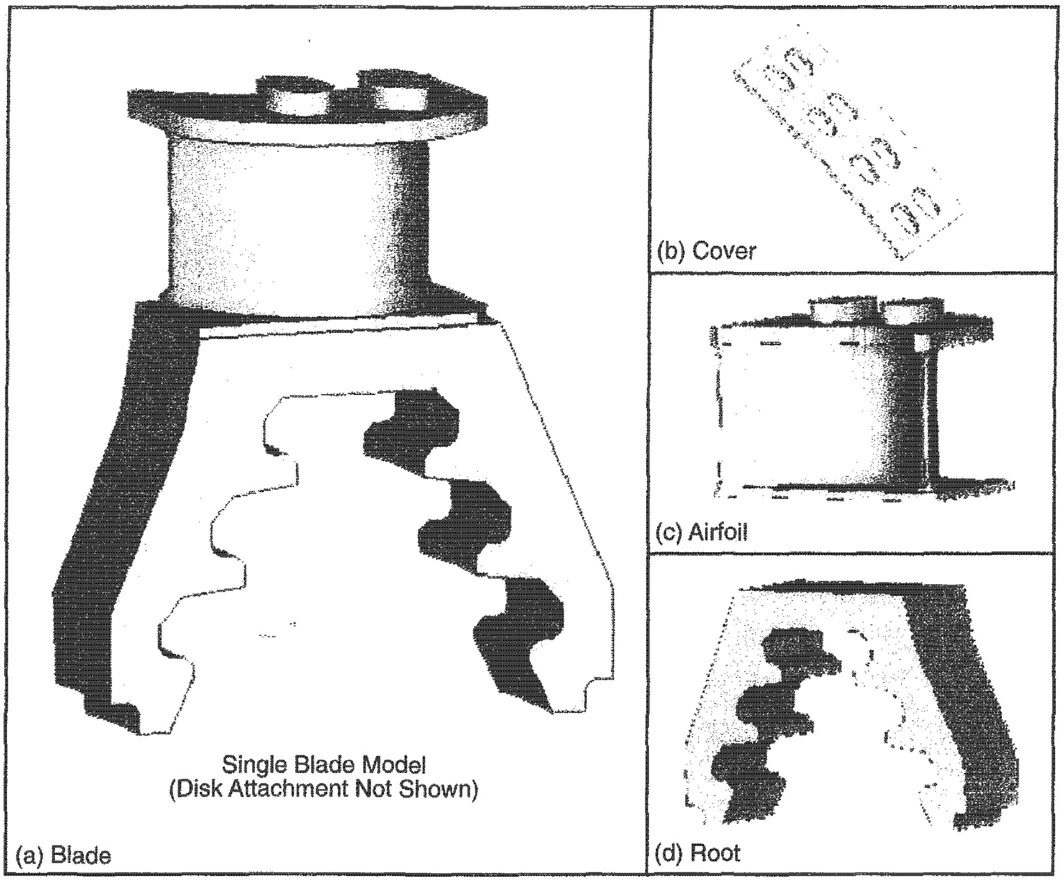


Figure 4-4
Features of the Control Stage Blade Finite Element Model

Note: The original FE model used to prepare this document is maintained as part of the support technology to assist operators during the course of an outage. For information on this model, contact the EPRI Project Manager for this *Guidelines for Reducing the Time and Cost of Turbine-Generator Maintenance Overhauls and Inspections* series.

4.3.4 Material, Mechanical, and Fatigue Properties

Basic mechanical properties describing the materials used to manufacture this blade are referenced in Table 4-2. The material properties used to perform the stress and frequency analysis are shown in Table 4-3. Properties used to assess crack initiation resulting from LCF and HCF are shown in Table 4-4. Additional relevant material properties associated with the operating environment are included in Table 4-5.

Table 4-2
Mechanical Properties Describing Blade Material

Blade Material: AISI: 422SS at 932°F (500°C)		
Bar Stock? __X__Yes ____No	Envelope Forging ____Yes __X__No	
Mechanical Properties	**Blade/Cover**	
Tensile Strength [S]	96 ksi	662 MPa
0.2% Yield Strength [Sy]	82 ksi	565 MPa
Elongation (%)	25	
Reduction of Area (%)	65	
Charpy V-Notch	40 ft-lb	554 cm-kg
Hardness (HRC)		

Table 4-3
Material Properties Used in Structural Analysis

Material Properties	**Blade/Cover/Disk**	
Young's Modulus [E]	23,400 ksi	161,300 MPa
Poisson's Ratio	0.18	
Density	0.283 lbm/in^3	7.840 g/cm^3

Table 4-4
Material Properties Used for Fatigue Life Prediction

Fatigue Properties	Blade/Cover/Disk	
Fatigue Strength Coefficient [σ'_f]	145.8 ksi	1005 MPa
Fatigue Strength Exponent [b]	-0.094	
Fatigue Ductility Coefficient [ε'_f]	0.602	
Cyclic Hardening Exponent [n']	0.134	
Fatigue Ductility Exponent [c]	-0.665	
Hardening Coefficient [K'] - ksi (MPa)	150.9 ksi	1040 MPa
Fracture Toughness (K_{IC})	110 ksi-$in^{1/2}$	121 MPa-$m^{1/2}$
Threshold Stress Intensity LCF (ΔK_{th})	5 ksi-$in^{1/2}$	5.5 MPa-$m^{1/2}$
Threshold Stress Intensity HCF (ΔK_{th})	3.2 ksi-$in^{1/2}$	3.52 MPa-$m^{1/2}$

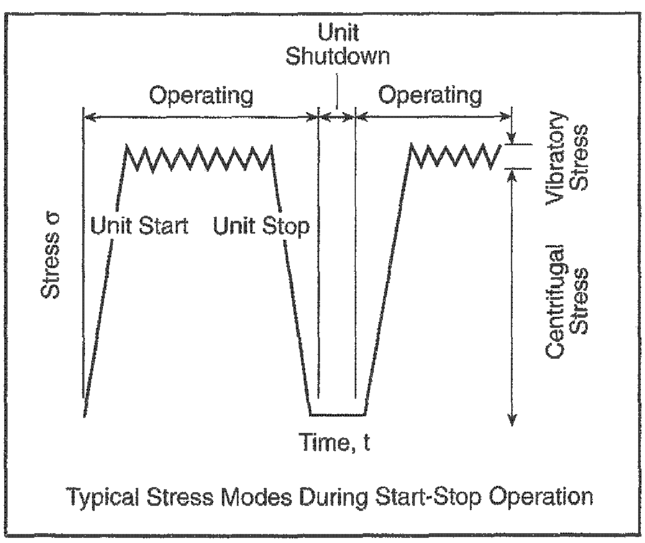
Table 4-5
Material Properties Related to the Operating Environment

Material Properties	Blade/Cover/Disk	
SCC Growth Rate* [da/dt]	NA	
SCC Threshold Value* [K_{ISCC}]	NA	
Thermal Conductivity**	15.8 Btu/ft-hr-°F	27.3 W/m-°C
Coefficient of Expansion**	6.40E+06 1/°F	11.50E+06 1/°C
* Not required unless the stage operates within or beyond the Wilson Line.		
**Not required unless the stage operating temperature is greater than 850°F (454.4°C).		

4.4 Steady Stress Results

4.4.1 Assumptions and Results

As shown in Figure 4-5, operating stress for blades can generally be divided into two types: steady and dynamic. (Partial arc operation that is unique to control stage blades is addressed separately.) To simulate the load conditions under full speed operation, the blade FE model was subjected to a combined steady-state centrifugal force and steam bending load. The centrifugal force used in the analysis assumed a rotational speed of 3600 rpm. For each blade, the tangential force was assumed to be 10 lb (4.5 kg) and the axial force 12 lb (5.4 kg). As with this case, the proportion of steady stress normally attributed to steam bending forces is typically less than 10% of the total steady force exerted on a blade.



Source: Turbine Steam Path Damage: Theory and Practice, EPRI, 1999

Figure 4-5
Relationship Between Steady and Dynamic Stress

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Centrifugal and bending stresses were calculated by assuming linear elastic behavior of the material, that is, the material is not allowed to yield during the simulation. This approach is acceptable for turbine blades because plastic deformation normally occurs only in the fillet regions of the root attachment and is, therefore, localized. Regions of local yielding are identified in the following results by comparing the magnitude of elastic stress against the yield strength of the material. The influence of any local yielding on fatigue damage is later accounted for directly in the LCF analysis.

Table 4-6 summarizes the results of the steady stress analysis as both maximum principal and equivalent stress. Profiles of maximum stress distribution for each design feature are illustrated in Figure 4-6 through 4-8 where pound per square inch (kg per cm^2) is the working unit. In the subsequent section of the design audit involving estimates of crack initiation, equivalent stress values are converted to true stress for those regions where the stress exceeds 50% of the yield strength. These regions are further identified on Table 4-6.

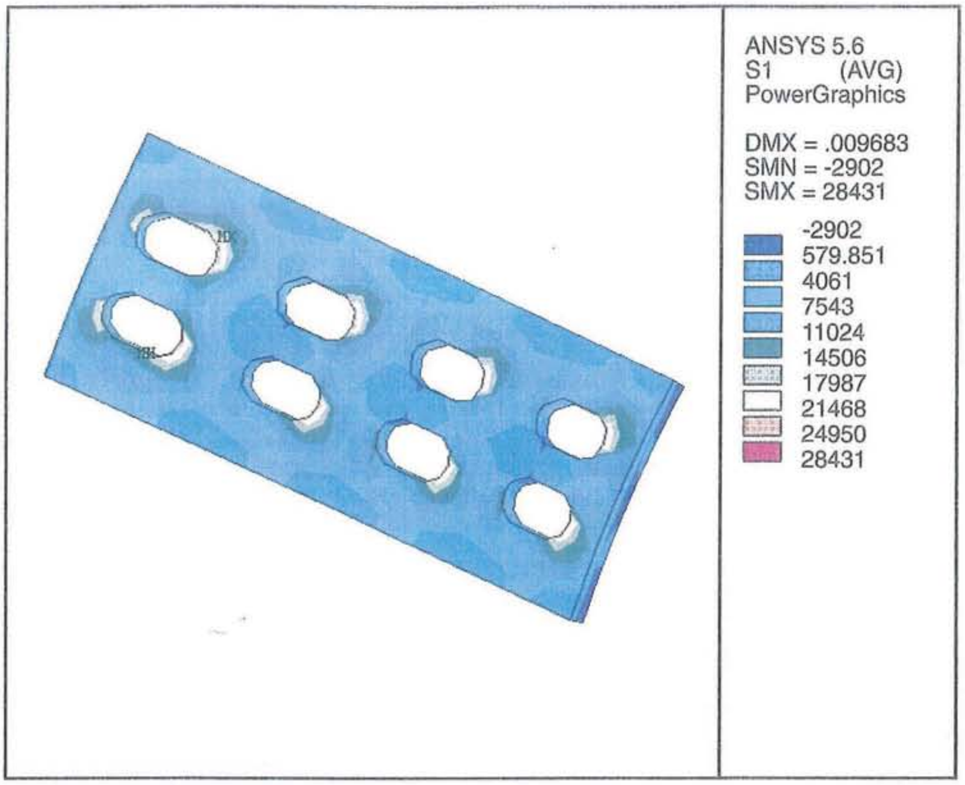
Table 4-6
Summary of Calculated Steady Stresses

Structural Feature Material Yield Strength: 78.0 ksi (537.81 MPa)	Max Equivalent Elastic Stress ksi (MPa)	Max Principal Elastic Stress ksi (MPa)	Local Yielding?** Yes or No	True Stress ksi (MPa)
Cover	35.31 (243.44)	31.58 (217.73)	No	30.4 (209.6)
Tenon	31.89 (219.88)	38.04 (262.25)	No	36.3 (250.3)
Tie Wire – Lashing Lug*	NA	NA	NA	NA
Airfoil – Leading Edge	19.25 (132.73)	21.80 (150.31)	No	21.0 (144.8)
Airfoil – Trailing Edge	19.25 (132.73)	24.53 (169.11)	No	23.6 (162.72)
Blade Root	57.54 (396.70)	59.62 (411.03)	No	40.4 (278.5)
Disk Attachment	62.96 (434.10)	53.55 (369.27)	No	34.8 (239.9)
* If not applicable, NA is indicated.				
** Yes is indicated if the reported elastic stress exceeds the material yield strength.				

4.4.2 Summary of Results

Referring to Table 4-6, the analysis indicates that a maximum principal stress of 38.87 ksi (268.0 MPa) occurs in the blade root at the corner filet of the uppermost pair of attachment hooks. Stress in the disk attachment is slightly lower, with a maximum of 53.55 ksi (369.27 MPa) predicted in the filet of the upper pair of hooks. Presuming the yield strength is 82 ksi (565 MPa) at 950°F (510°C), the inherent conservatism and general durability of the blade are reflected in the fact that no local yielding is predicted in the root attachments, that is, stresses are all below yield.

In terms of LCF, the early indications of damage would be in the root first and in the disk hook region second.



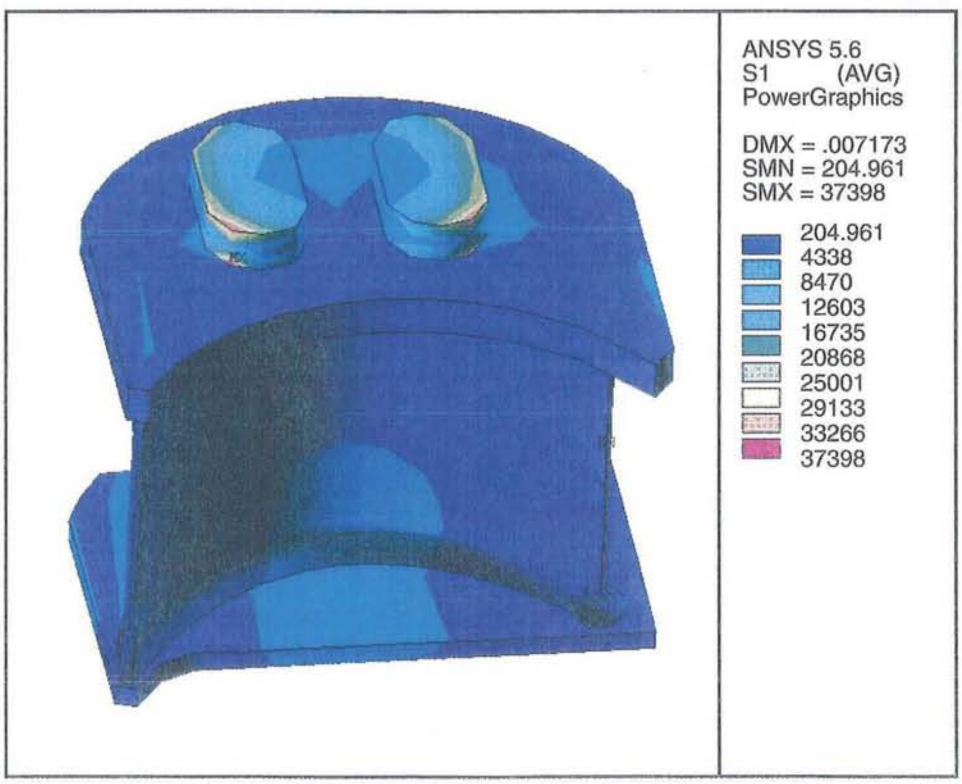


Figure 4-6
Distribution of Steady Stress in the Cover and Tenon

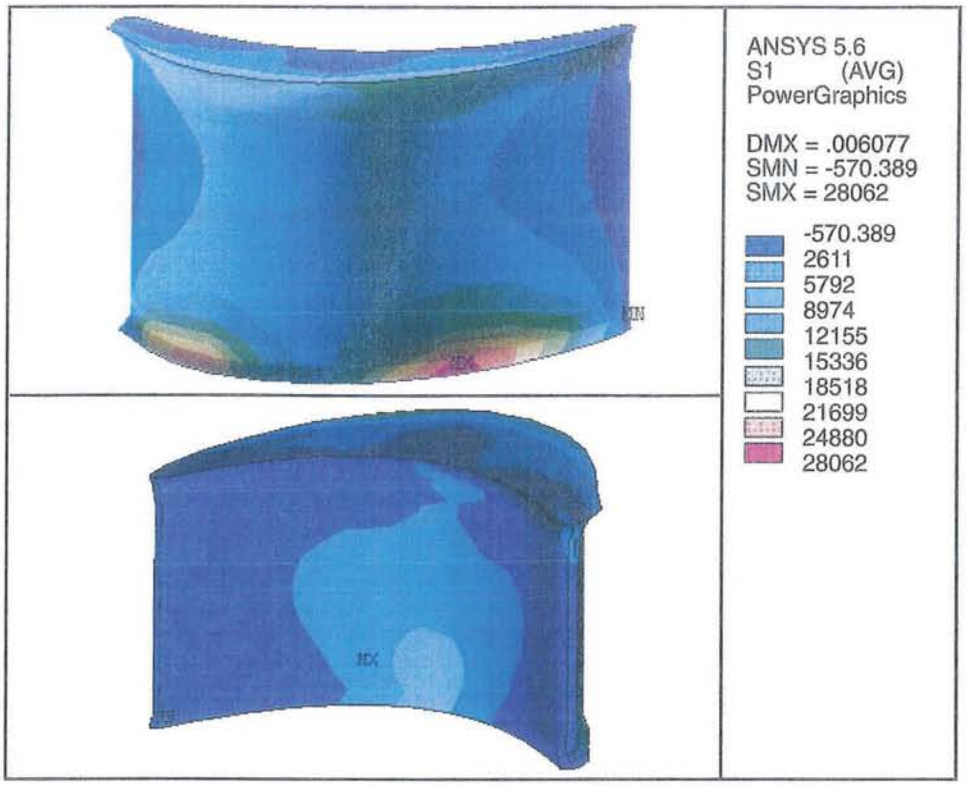


Figure 4-7
Distribution of Steady Stress on the Airfoil Leading and Trailing Edges

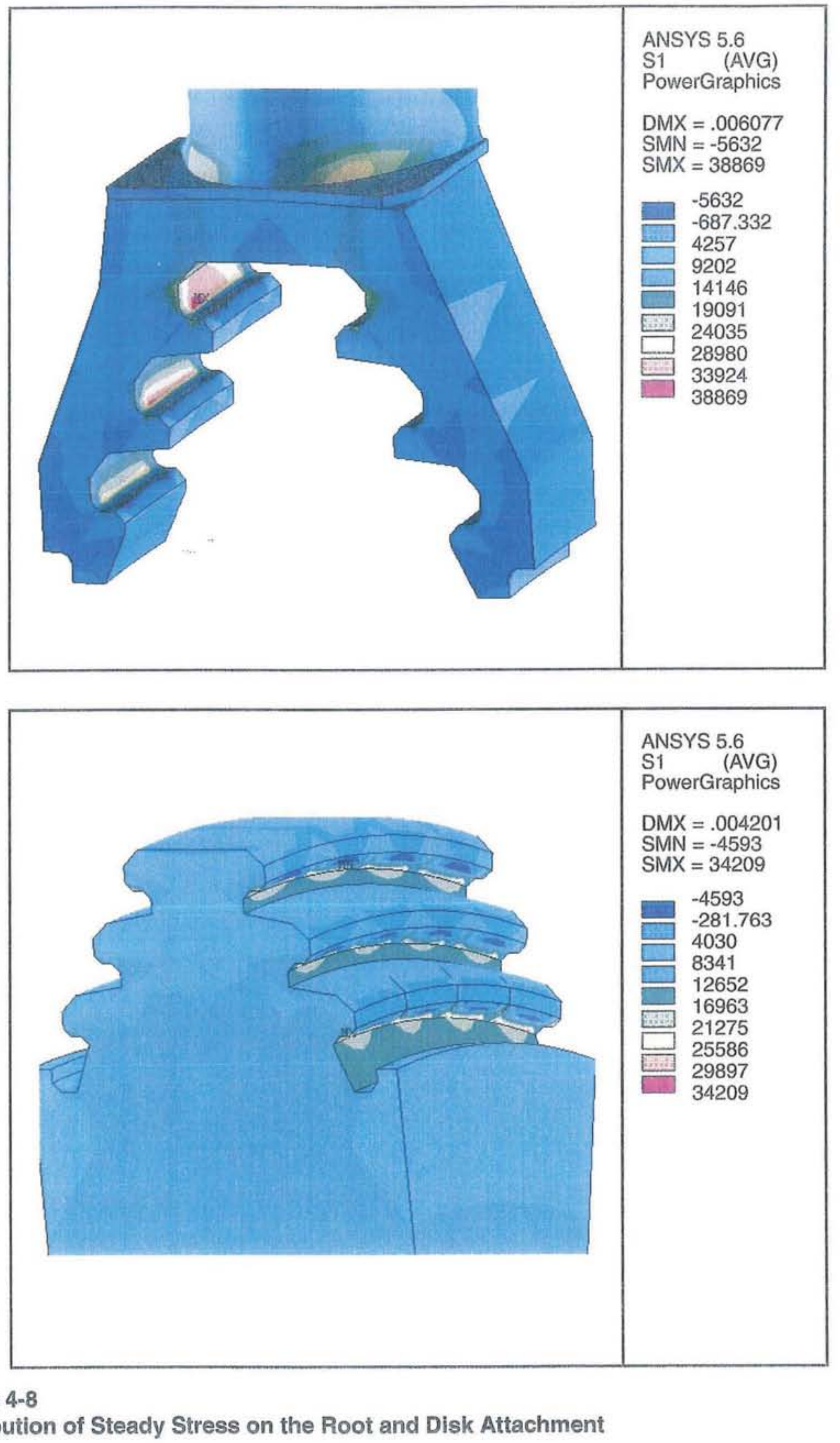


Figure 4-8
Distribution of Steady Stress on the Root and Disk Attachment

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4.5 Dynamic Analysis

4.5.1 Assumed Stimulus and Damping

For any steam turbine stage, the non-uniform flow field around the circumference provides a source of dynamic excitation that promotes blade-disk vibration during operation of the turbine. The forcing experienced by any blade on the disk can be separated into different frequency components, which are referred to as *per-rev forces*. For the purpose of designing reliable blades, the magnitude of a given per-rev force is approximated as a stimulus or the ratio of the dynamic force amplitude over the steady steam bending force. Generally, the stimulus experienced by blades in the last stages of a low-pressure turbine are more significant in contrast to high-pressure blades because they are operated in a much lower frequency region where the per-rev forces are normally the strongest.

Because direct measurements of blade vibration are rarely available for a given unit, a reasonable stimulus should be selected to calculate dynamic stress. For the purpose of this document, the stimulus was estimated at 0.6% for high order excitation. Blades should be able to accommodate the HCF produced at these stress levels despite the large numbers of cycles that are accumulated over years of operation. Conversely, premature failure resulting from HCF is often an indication of resonant vibration attributable to design inadequacy.

The stimulus experienced by control stage blades at partial arc operation is considered as a special case and is, therefore, approached in an advanced study. For HP blades, operation in a partial arc condition (that is, less than 50% load) is most likely to be the more important potential source for a dynamic problem. This special case is examined in Section 4.5.4.

To assess the vibration of any mechanical system, the counterpart to stimulus and response is the available damping. For blades, damping is derived from three sources: material, mechanical, and aerodynamic. Consistent with the features of this blade, a damping ratio of 0.08% over critical damping was assumed. For turbine blades, the majority of available damping comes from Coulomb (friction) damping and the aerodynamic force that is present. Material damping is generally inconsequential as a mechanism for opposing or inhibiting vibration. Mechanical damping is most effective when design elements such as tip linkages and "z" lock mid-span lugs are used.

4.5.2 Natural Frequencies and Critical Modes

Because blades experience a significant centrifugal force at full speed, the natural frequencies shift as a result of the effects of stress stiffening and spin softening. The shift is calculated by the analysis to identify the margin available at normal operating speed to avoid resonance during operation. The results of the frequency analysis at zero rpm are also provided to give operators another way to calibrate modal test frequencies taken during a maintenance outage.

In general, frequencies expected at full turbine operating speed are checked by relating them to zero rpm frequencies, that is, without the influence of stress stiffening or temperature effects. (It should be noted that to perform such a comparison requires that both the proper equipment and approach be applied to get accurate modal data for a legitimate comparison. To make a legitimate comparison, the nodal diameters of the disk must be tested, which normally requires a large shaker that can be linked to the disk. Looseness at disk attachments, tie wires, or covers can create structural nonlinearities that will compromise the quality of the test data.)

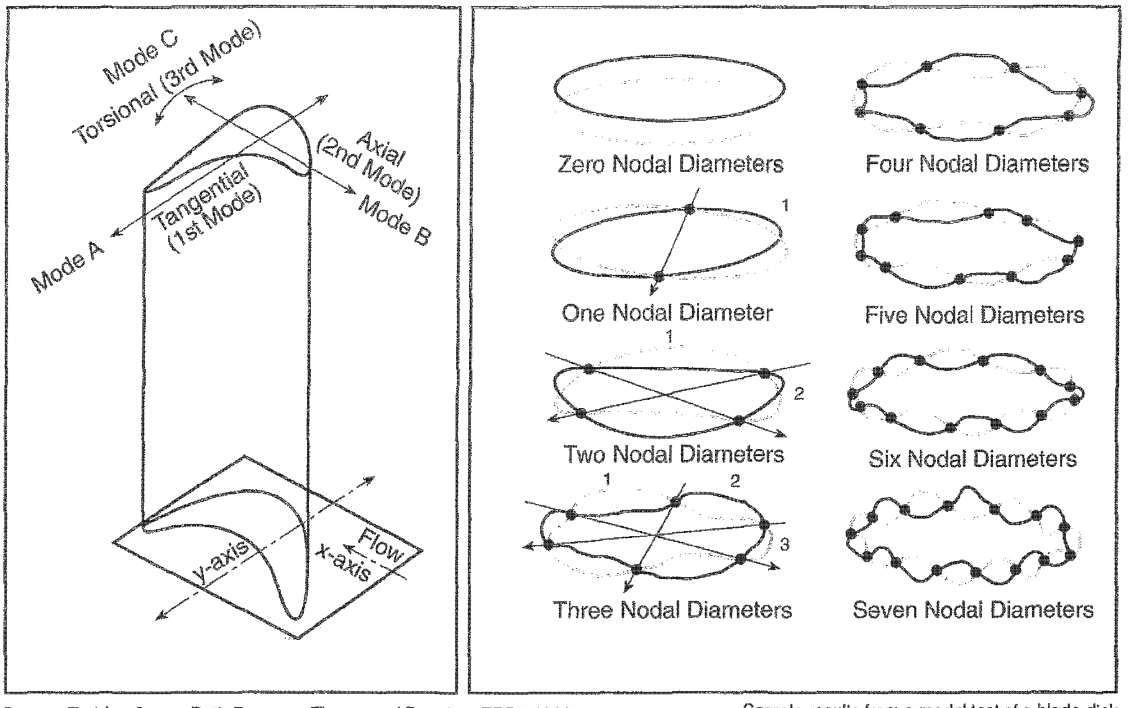
For longer blades, a frequency margin of ±10 hertz from the nearest per-rev engine order normally represents adequate protection from resonance, although operating margins of a few hertz will significantly reduce dynamic stresses. For shorter blades, where such control over the frequencies is impractical, the design is expected to be able to withstand the dynamic forces at resonance.

Because turbine blades are installed on circular disks or drum-type rotors, the motions of the blades are superimposed on the flexures of the disk, creating a complex dynamic system. In the audit results, fundamental modes refer to the displacement of the blades in the axial, tangential, or torsional direction. The pattern of displacement formed by the disk is identified by its nodal diameter. Both are illustrated in Figure 4-9.

Together, families of mode shapes are associated with each nodal diameter of the disk. The way to reduce this complex dynamic behavior into an understandable format is by using the interference diagram, shown in Figure 4-10. For a mode to be strongly excited in a blade-disk structure, the forcing frequency not only has to match the natural frequency of the structure (as presented in the Campbell diagram), but also the distribution of the force must match the mode shape. On the interference diagram the number of per-rev excitations and the nodal diameter number must be equal or compatible as illustrated in Figure 4-11.

The interference diagram quickly reflects whether both conditions are satisfied. If the nearest nodal diameter frequency is 10 hertz or greater from the mode, the mode is considered to be detuned. If the margin is less than 10 hertz, then there is a concern for resonance. Generally, HP and IP blade designs do not allow their frequencies to be precisely controlled. Instead, they are designed to be sufficiently rugged to cope with the dynamic stresses that may occur if any mode encounters a condition of resonance.

In the case of control stages, the roles of natural frequencies, dynamic stresses, and HCF are examined in the context of partial arc operation. Similar to the resonance of LP blades, it is under this operating condition that the potential for damage is most significant.



Source: Turbine Steam Path Damage: Theory and Practice, EPRI, 1999

Sample results from a model test of a blade-disk structure that shows the distribution of node ports around the disk circumference, identifying the lines and characterizing the disk mode shapes.

Figure 4-9
Nomenclature Describing Blade and Disk Vibration Modes

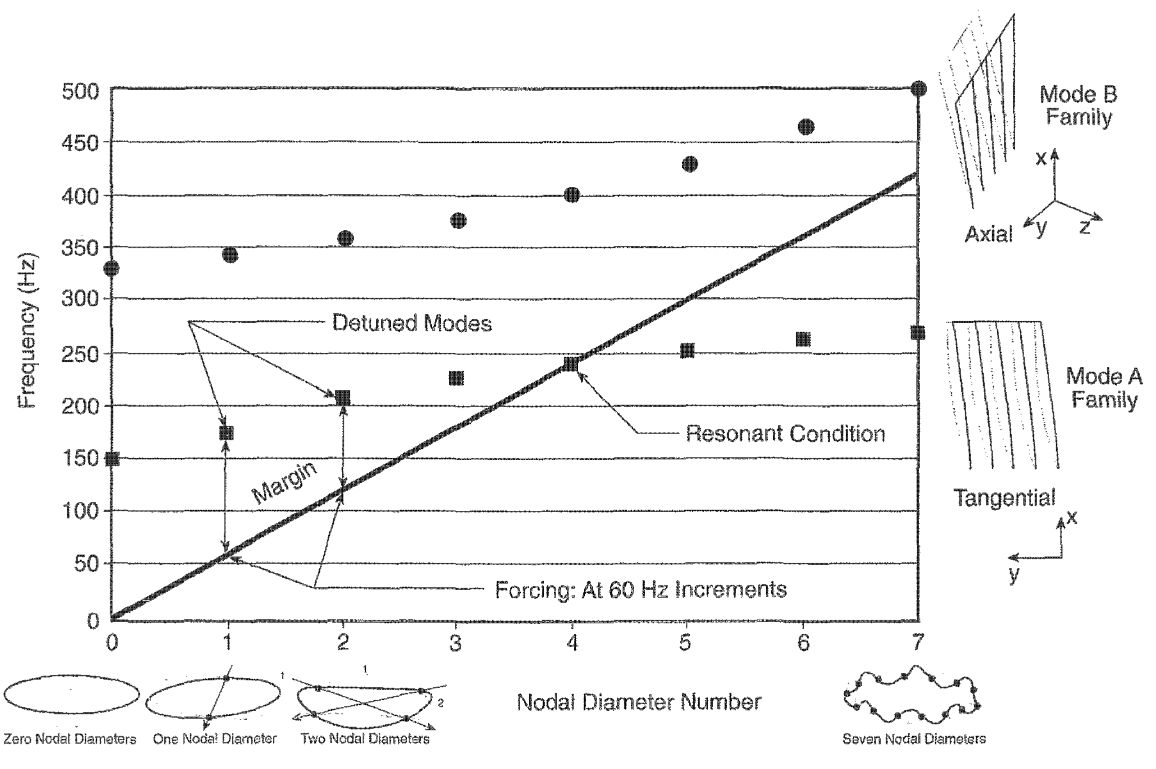


Figure 4-10
Nomenclature of an Interference Diagram

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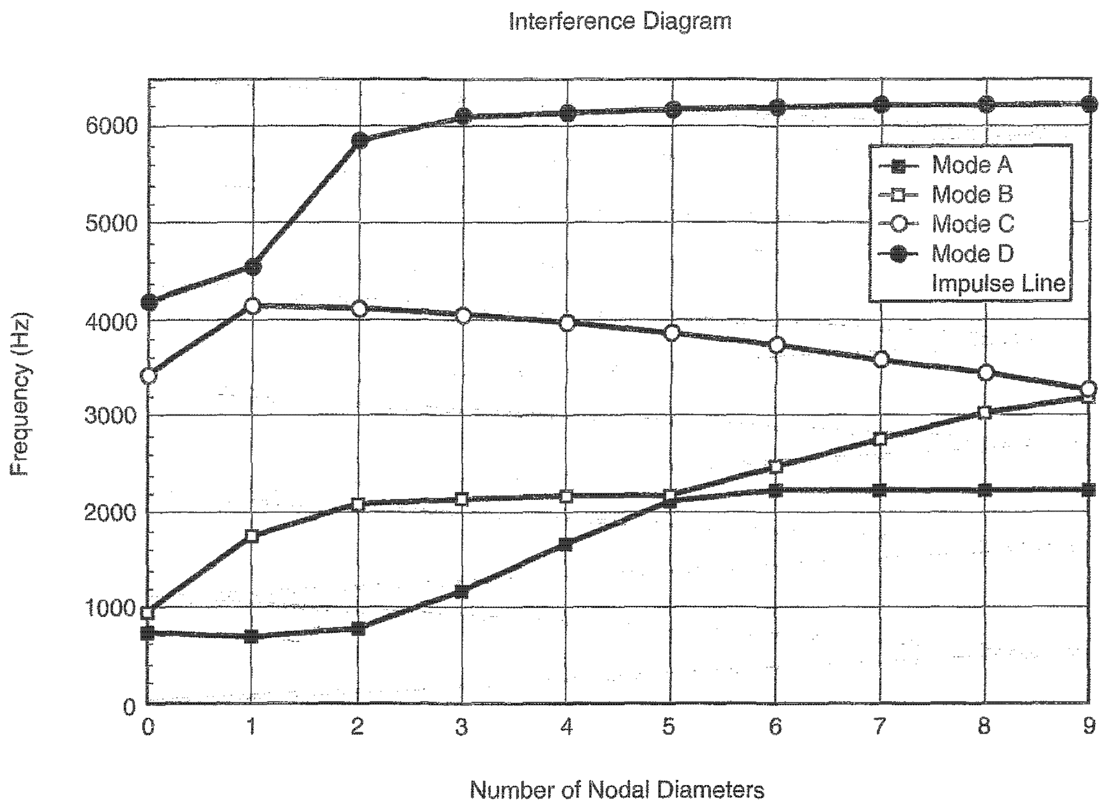

Figure 4-11
Interference Diagram at 3600 RPM

4.5.3 Frequency Results

Results from the blade-disk frequency analysis are summarized in Tables 4-7 and 4-8, and plotted in Figure 4-11. The first four nodal diameter (ND) mode families are reported as families A–D. Nodal diameter modes identified on the interference diagram with the narrowest margins are highlighted in Table 4-7. Table 4-9 outlines these nodal diameter modes.

Table 4-7
Blade Disk Natural Frequencies (at Operating Speed)

	Stage Nozzle Passing Frequency 7680 Hz			
	Frequencies Shown are: X Calculated __Measured			
Nodal	Mode Family			
Diameter	A	B	C	D
0	737	944	3418	4167
1	691	1732	4153	4549
2	764	2068	4114	5868
3	1161	2128	4052	6094
4	1663	2157	3969	6131
5	2107	2179	3865	6159
6	2194	2472	3741	6182
7	2205	2770	3597	6201
8	2211	3017	3436	6213
9	2213	3184	3297	6217

Note: Frequencies with less than a 10-hertz margin from the nearest per-rev forcing are not necessarily an indicator of a possible HCF problem. Under the criteria presented in Section 4.1, they represent the modes that are recommended for further evaluation in terms of their dynamic stress.

Table 4-8
Blade Disk Natural Frequencies (at Zero RPM)

	Stage Nozzle Passing Frequency 7680 Hz			
	Frequencies Shown are: X Calculated __Measured			
	Mode Family			
	A	B	C	D
0	734	943	3407	4163
1	687	1730	4149	4541
2	759	2064	4110	5859
3	1156	2123	4048	6091
4	1658	2152	3965	6128
5	2103	2174	3861	6155
6	2188	2468	3737	6179
7	2199	2765	3593	6198
8	2206	3013	3432	6210
9	2208	3180	3292	6214

Note: At zero rpm, the frequencies shown in Table 4-8 represent blade-disk modes that have no centrifugal stress applied to them. As stated, these frequencies will be altered to those shown in Table 4-7 when stress-stiffening and spin-softening are applied. Zero rpm frequencies can be used in conjunction with modal testing to check the "tuning" of new or used blades. However, to make a legitimate comparison with the frequencies shown in Table 4-8, the tests must recreate the conditions assumed in the simulation (for example, proper clearance/shrink-fit between assembled parts) and must sufficiently excite the disk to obtain the blade-disk modes.

Table 4-9
Modes with the Lowest Margin of Detuning from Resonance

ND Mode Family	ND# and Frequency	Nearest Engine Order	Frequency Margin
Mode A	ND 3 at 1161 Hz	21 per-rev at 1260 Hz	99 Hz (8%)
Mode B	ND 2 at 2068 Hz	34 per-rev at 2040 Hz	28 Hz (1.5%)
Mode C	ND 7 at 3597 Hz	61 per-rev at 3660 Hz	63 Hz (1.7%)
Mode D	ND 5 at 6159 Hz	103 per-rev at 6180 Hz	21 Hz (<1%)

Note: In the case of shorter blades that operate with natural frequencies in the range of 1500 hertz and higher, the impulse line is extended (or reflected) to identify a potential resonance with the higher order harmonics.

4.5.4 Dynamic Stress Under Partial Arc Operation

Studies of partial arc operation suggest that the pressure difference across the control stage can be as much as 400% higher than in the normal mode of operation, particularly at single admission operation. The transient forces generated at these conditions are made up of large impulses on the blade, accompanied by higher steady steam forces. Operating in partial arc operation is, therefore, of special concern to control stage blades because it represents the most likely source of maximum dynamic stress and HCF damage.

To suggest the magnitude of the dynamic stresses that might occur under partial arc operation, a profile was generated of the transient steam bending force. The forcing profile was derived by throughflow analysis using a heat balance diagram of the high-pressure stage. Admission corresponding to 30% of full load was selected to represent the worst case that other partial arc conditions could be compared against. A partial arc admission response was selected to reflect the forces that any blade on the row might experience as it went through a complete cycle of partial arc operation. The transient forcing profile was then used to compute the total dynamic stress experienced by the blade at its maximum dynamic response. Based on this response, the total dynamic stress experienced by the control stage blade at its maximum point of dynamic response was calculated. These results are summarized in Table 4-10.

To identify a profile for each of the different modes of vibration, dynamic stress was calculated under an assumed resonant condition for a nodal diameter mode selected from each family (A–D). Figures 4-12 through 4-15 show the resulting stress distributions for each of the first four ND modal families.

Table 4-10
Estimated Dynamic Stress for Selected Modes at Partial Arc Operation

	Mode A		Mode B		Mode C		Mode D	
Natural Frequency (Hz)	1161		2068		3597		6159	
	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa
Cover (Shroud/Integral)	0.08	0.55	0.12	0.80	0.03	0.24	0.11	0.74
Tenon	0.20	1.38	0.20	1.38	0.08	0.55	0.55	3.81
Airfoil – Leading Edge	0.30	2.07	0.10	0.69	0.07	0.51	0.12	0.80
Airfoil – Trailing Edge	0.20	1.03	0.44	3.03	0.16	1.10	0.86	5.92
Blade Root	0.40	2.96	0.50	3.45	0.19	1.36	0.98	6.77
Disk Attachment	0.40	2.55	0.47	3.24	0.16	1.11	0.78	5.35

During periods of partial arc operation, it is generally assumed that dynamic stress will be equal to or significantly greater than these resonant stress values. However, for the maintenance engineer tasked within inspecting these blades for symptoms of fatigue, it should be noted that the distribution and locations of maximum dynamic stress shown in the following figures remain the same.

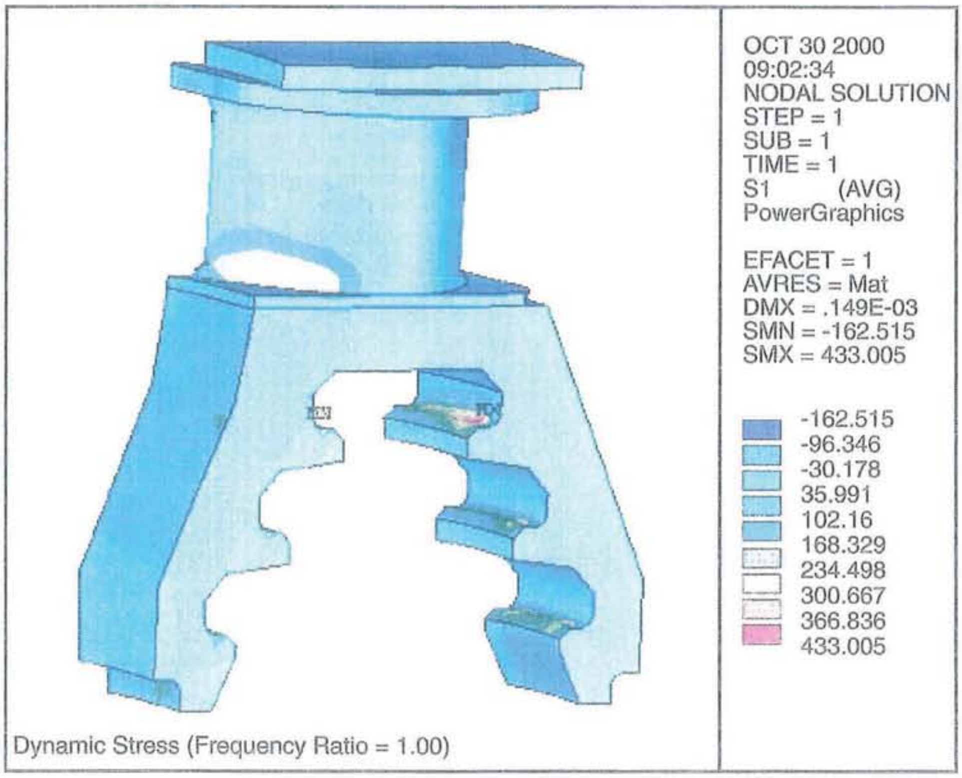

Figure 4-12
Resonant Dynamic Stress Profile for Mode A

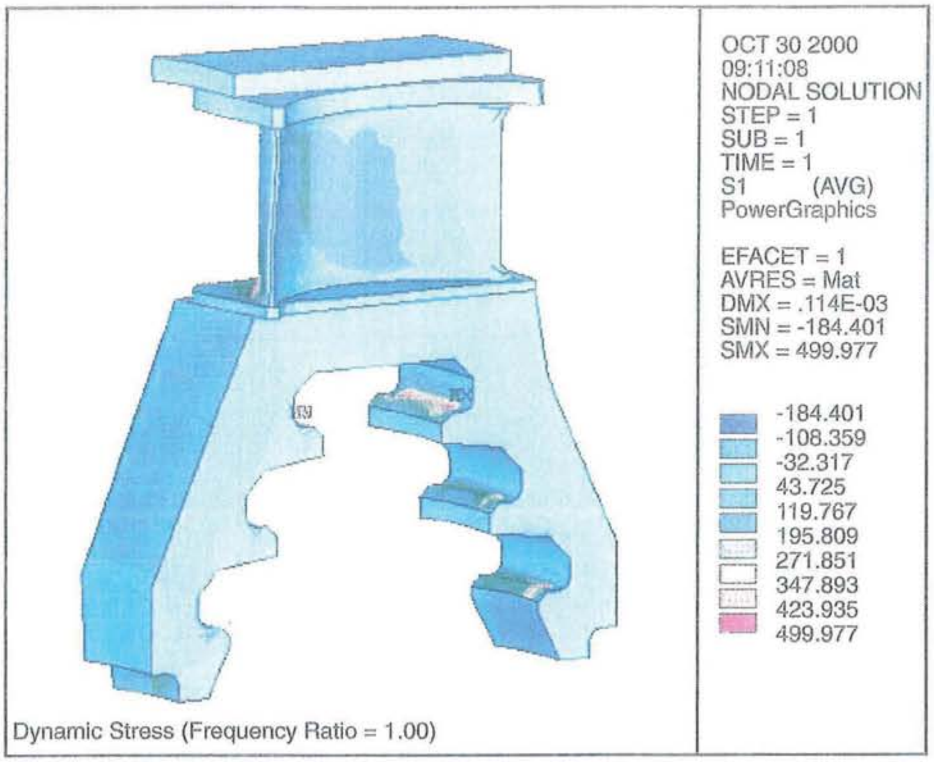

Figure 4-13
Resonant Dynamic Stress Profile for Mode B

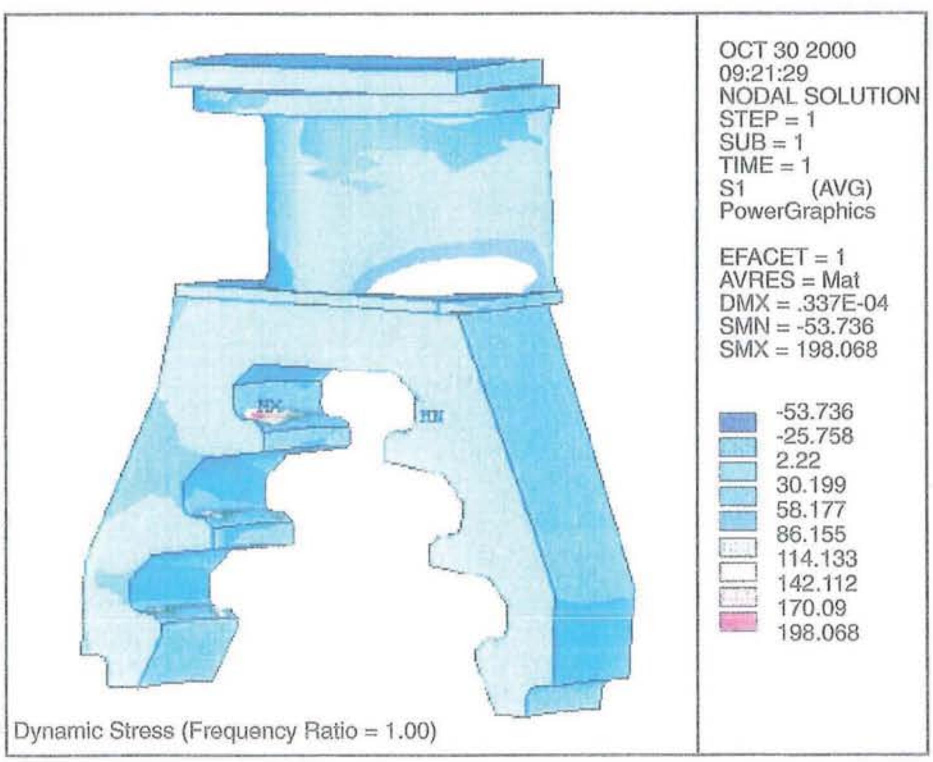

Figure 4-14
Resonant Dynamic Stress Profile for Mode C

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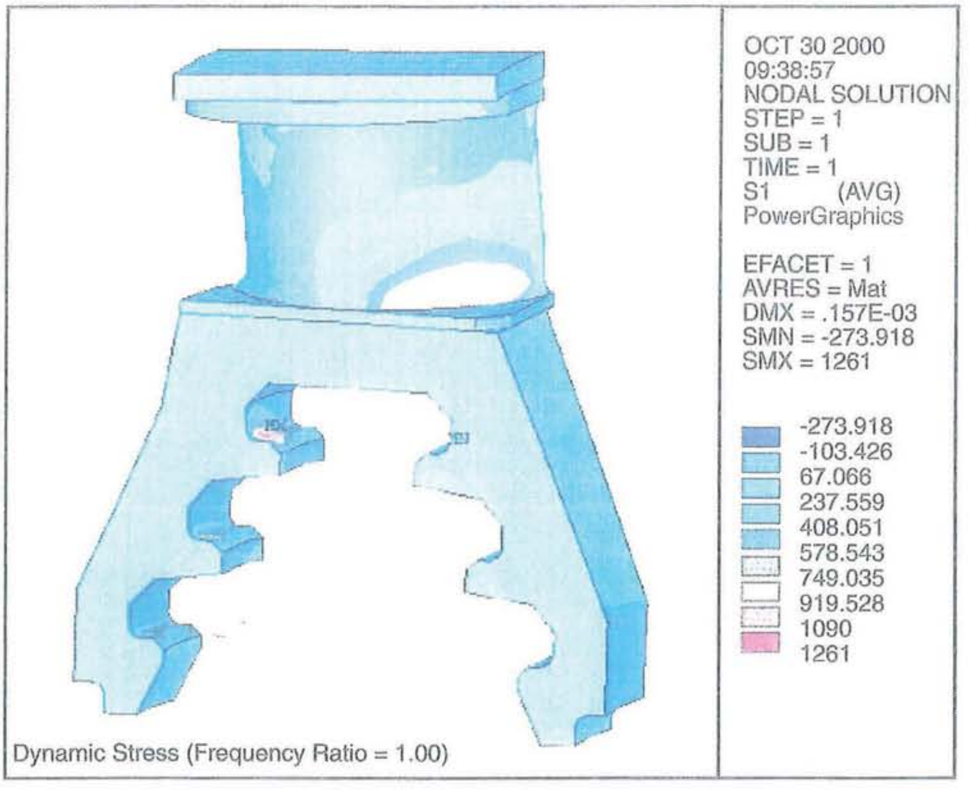

Figure 4-15
Resonant Dynamic Stress Profile for Mode D

4.6 Guidelines for Inspection and Risk Assessment

As parts remain in service longer and the intervals between inspections are increased, there is a greater chance of finding damage or wear to the rotating components, particularly at the front and back end where the environment is the most aggressive. Because these parts can significantly affect the critical path of an outage, this portion of the guideline is designed to assist an engineer with the following:

- Anticipate which parts may need to be replaced
- Ensure that future inspections are focused on key locations where fatigue is most likely to appear
- Make a quick assessment as to whether any found damage presents a low or high risk of failure prior to the next maintenance interval

For control stage and first reheat buckets/blades, the remaining portion of this guideline features a probabilistic treatment of low-cycle fatigue (LCF), high-cycle fatigue (HCF), creep rupture (CR), and solid particle erosion (SPE). It is noted that although HP and IP blades also experience low-cycle fatigue (due to start-stop cycling of the turbine) and high-cycle fatigue (promoted by vibration of the blades during periods of operation) in the same manner as LP blades, HP/IP blades are generally designed with the ruggedness and durability to accommodate the damage caused by these mechanisms. Compare the calculated steady stresses as shown in Volume 6 (for example, Table 1-6) for a variety of HP/IP blades with those of Volume 7 (Table 1-6) for LP blades, and it is evident that the steady operating stresses in HP/IP blades that drive low-cycle fatigue are typically lower because the components are smaller. The estimates of LCF presented in this section are therefore primarily to show the relative difference between HP/IP blades and their LP counterparts.

Because HP/IP blades are much shorter than their LP counterparts, the natural frequencies of HP/IP blades are much higher and more difficult to "tune" with the same precision applied to the longer LP blades. Instead of avoiding resonance of the fundamental modes, HP/IP blades are instead designed to withstand the stresses and HCF caused whether they happen to operate in resonance or not. Because their frequencies are normally much higher than LP blades, vibration involves a much higher per-rev harmonic of forcing, with a much lower stimulus causing dynamic stresses to fall below 1 ksi (6.9 MPa) or well below the threshold where HCF is of concern. However, control stages are unique in that they can operate for periods in a condition of partial steam admission, as discussed in a previous section of this guideline.

Under partial arc operation, significant dynamic stress may sometimes be generated. The potential damage under partial arc operation is therefore examined as a special condition of HCF. However, as previously noted, the dynamic stresses applied in the treatment of high-cycle fatigue are for an assumed worst case scenario and where the damage would be limited strictly to the total hours operated in this condition.

4.6.1 Using These Guidelines

4.6.1.1 Planning

Stresses obtained from the design audit are extrapolated to first calibrate the inherent resistance of the blade to LCF (steady) and HCF (dynamic). These results show locations on the component where fatigue is likely to appear (initiate) first, particularly in parts that have seen extended service. This approach also accounts for the fact that fatigue damage is not linearly proportional to steady or dynamic stress, particularly in regions of local yielding, for example, the LCF damage caused from cycling at 50 ksi (345 MPa) steady stress is not simply 50% (or half as much) of that caused at 100 ksi (690 MPa).

Locations of maximum steady stress are likely to be areas most susceptible to creep damage in high pressure/high temperature blades. Locations of maximum dynamic stress should be communicated to those responsible for performing NDE/NDT on the row. These locations represent areas that may become susceptible to HCF in the presence of pits, erosion or corrosion.

If evidence of fatigue is detected or suspected, some closed form formulations are offered to make quick estimates of crack growth rates and allowable crack lengths at different locations in the blade or disk attachment. These can be used to determine how immediate the need is to replace these components, that is, what is the risk of operating the blades for a limited period until the next convenient opportunity to repair or replace them.

4.6.1.2 Making Run-Repair-Replace Decisions

Uncertainties in both material properties and stresses obtained from the audit are treated probabilistically. The potential for the initiation or propagation of cracks is plotted against either hours of operation, or number of start-stop cycles to let the maintenance engineer assess where on the probability curve the machine-specific operating history of the unit would place them. Since the probabilities are stress-based, a "family" of curves is generated to show how the estimated probability might change for different locations or levels of stress that the engineer might chose to track. Estimating or assuming what the level of stress might be at a location of damage allows an engineer to further extrapolate the probabilities to represent any given location or to see how the probabilities might be affected if a safety factor were applied to the stress. For example, how much does the chance of a failure increase if the stress in the region of concern is doubled or tripled?

After an appropriate failure curve has been selected (based on the operating hours, years in service, or number of start-stop cycles the component has experienced), the engineer can further use the probability curves to establish the probability (or relative increase in the probability) of a failure at regular intervals of continued service. As noted, service is reflected using a scale that is the most appropriate to the damage mechanism being assessed, for example, years of cumulative operation at partial arc operation for HCF and years for creep.

Ultimately, the maintenance engineer must establish with management what is considered an acceptable level of risk and weigh the hazards accordingly. With the advent of deregulation, acceptable risk is often dictated by the demand for and value of power at the time an outage is to be performed. That is, although the predicted risk might be considered as generally unacceptable or high, the relative difference between the present probability of failure and the probability of failure after three or six months of additional operation might be sufficient to justify a decision to tolerate the damage for a limited period.

To assist in this final step, the probabilistic results are presented using a hazard risk assessment matrix originally produced for the Department of Defense. MIL-STD-882C "Military Standard System Safety Program Requirements" January 1993, was selected because it offers a system of classification that separates levels of probabilities into seven basic categories and suggests how to interpret them in terms of their potential risk. Although the matrix is offered as a standard, it should be noted that the relative change in the predicted probability for a given type of failure might be better used to make short-term run-repair-replace decisions, based on how much additional risk might be tolerated.

4.6.2 Design Audit Versus Damage Assessment

As shown in the tables earlier in this section, the design audit produces discrete stress values, frequencies, or predicted fatigue life. This detailed knowledge may be used to estimate the probability of a failure if each of the aforementioned elements (materials, stress, damage) are described as a statistical distribution and associated with a relevant measure of the unit's operating history. The statistical distributions reflect real world factors that are associated with producing the material, machining multiple parts, and assembling a number of them together to form a working structure, resulting in nominal differences that make each blade and blade-disk unique. A probabilistic treatment reflects this uncertainty as a consequence, that is, the chance that any given component might be more or less susceptible to one of the mechanisms expected to be present during operation.

In these guidelines, the input for any selected variable has been represented as a log-normal distribution about a mean. It should be noted that the procedure used to develop the curves presented in this guideline can be refined if details of the input data are available.

To further assist in the interpretation of the probabilities shown in this guideline, the maintenance engineer is referred to damage risk classifications associated with different levels of probability, ranging from *improbable* (1.0E-7) to *frequent* (1.0E-1). It should be noted that this is a military standard applied to vehicles such as aircraft where the tolerance for any cracking is very low, that is, this standard should be considered very stringent.

4.6.3 Low-Cycle Fatigue

In this portion of the guideline, low-cycle fatigue damage is first assessed in terms of the number of cycles when cracks are predicted to initiate (not propagate to failure). LCF is assessed primarily as the consequence of start-stop cycling under the influence of steady (centrifugal) stress at different regions of the component.

As mentioned, because steady stresses for HP/IP blades are generally low, that is, below 50 ksi (345 MPa), the possibility for an LCF crack is not typically a concern. In this guideline, LCF is still addressed in a logical sequence in terms of

- The design's inherent *resistance*
- The *probability* for LCF cracks to initiate
- Its *tolerance* of any cracks/flaws, either assumed or detected.

In general, as the curves show, the probabilities for LCF cracks are remote.

Regardless of the probability of their appearance, if LCF cracks are detected and measured, estimates of crack growth rates under LCF at different locations are provided. These estimates offer a general indicator of the number of start-stop cycles that might be tolerated and assist in the assessment of whether there might be sufficient remaining life to reach the next planned outage if the principal damage is essentially due to the start-stop duty of the unit.

4.6.3.1 Resistance to LCF

Table 4-11 reflects the inherent resistance of the blade design by showing the estimated number of start-stop cycles before cracks are predicted to occur at different regions of the blade. The original elastic stress results shown in Table 1-6 are converted to true stress using Neuber's method (see Volume 4, Section 1.6.3, "General Requirement: LCF – Crack Initiation") and the material properties previously identified in Table 4-4 in order to estimate the amount of plastic strain that would occur for each start-stop cycle, and the number of cycles that would be expected to produce an LCF crack commensurate with this magnitude of plastic strain.

Table 4-11 identifies where a blade is most likely to experience or first exhibit cracking due to LCF, particularly if the unit is cycled frequently. As noted in the table, the predicted LCF is negligible for regions of the design where stress remains below the yield strength of the material. Because steady stresses are normally highest in the root/disk attachments of LP blades, this is where they are generally most susceptible to LCF and creep.

Table 4-11
LCF Crack Initiation Life for Identified Regions of Local Yielding

Structural Feature	True Stress		Plastic Strain (ε_p)	Start-Stop Cycles
	ksi	Mpa		
Cover	30.4	209.6	3.86E-08	1.06E+15
Tenon	36.3	250.3	1.70E-07	1.13E+14
Airfoil – Leading Edge	21.0	144.8	2.30E-09	7.38E+16
Airfoil – Trailing Edge	23.6	162.7	5.49E-09	1.99E+16
Blade Root	40.4	278.5	4.79E-07	2.40E+13
Disk Attachment	34.8	239.9	1.17E-07	2.00E+14
True Fracture Ductility (ε_f) Applied:				0.602
Fatigue Ductility Exponent © Applied:				-0.665

4.6.3.2 Probability of LCF Initiation

To aid the engineer in determining the potential risks for an LCF problem developing in this component, Table 4-12 lists the probabilities associated with its initiation in a blade comprised of 422 SS materials where the mean stress of the log-normal distribution used in the probabilistic model was increased by increments of 50 ksi (345 Mpa). The resulting curves shown in Figure 4-16 bound a possible 60–100 ksi (414–690 Mpa) that extends throughout a typical HP/IP blade. The probabilities are shown at each increment over a history of 100–1500 start-stop cycles to provide a way to establish the relevant probability to a unit with a known history.

It should be noted that because of the remote probability for LCF in high-temperature components, no published data exists on the cyclic material properties at the operating temperatures of interest. The curves, therefore. Reflect the properties of 12% chrome steel, extrapolated to the temperature region of interest.

To establish the probability of LCF initiation at the time of a planned inspection/outage, the maintenance engineer must reference the curve to the total cycles experienced by the machine. The increased possibility that LCF cracks will develop before the next interval is determined by projecting the number of cycles the unit is likely to accumulate before the next inspection interval and referencing this to the appropriate stress-damage curve. It is stressed that model is associated with the probability that LCF will initiate (as a prelude to eventual propagation and failure). It does **not** represent the end of service life, but it does indicate the likelihood that LCF may be present, particularly as the unit accumulates more cycles. As the plot shows, given the steady operating stresses previously shown for this blade (refer to Table 4-6), the probability for LCF is generally remote, even after 1500 start-stop cycles.

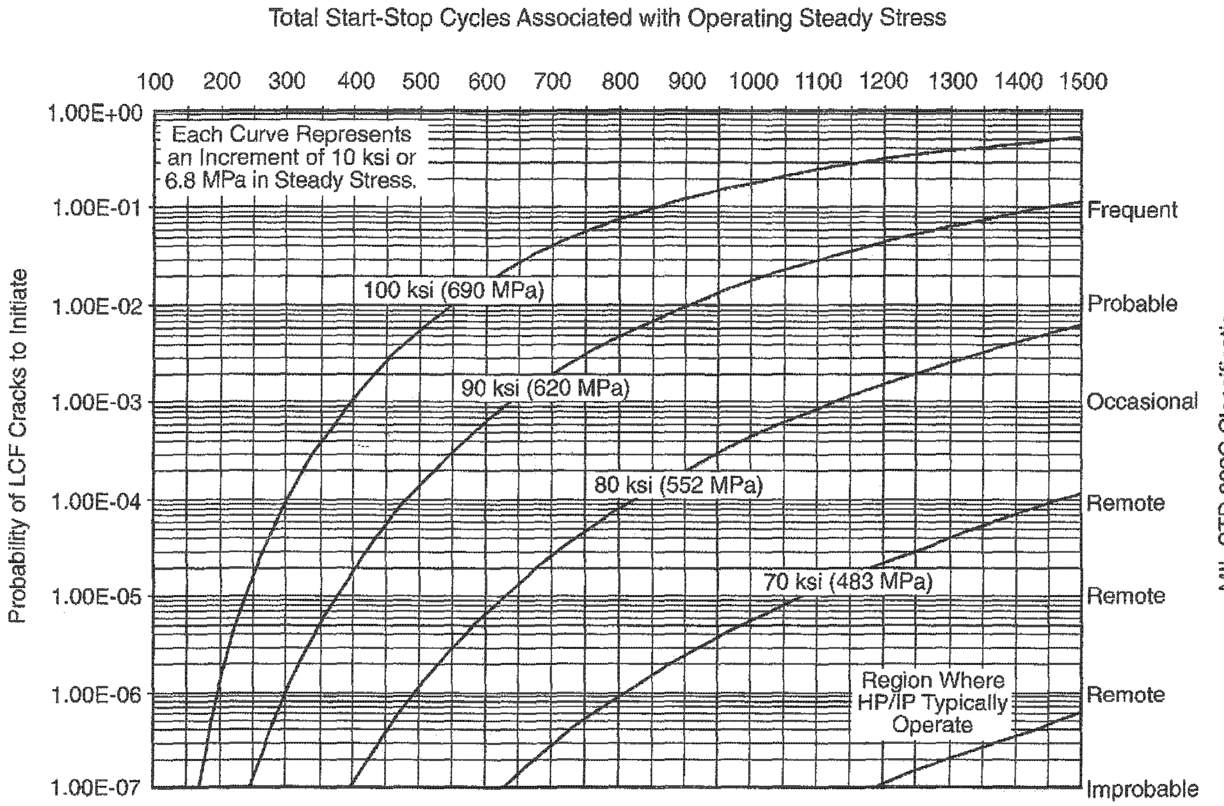

Figure 4-16
Probability of LCF Cracks Initiating at Different Levels of Operating Stress

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Table 4-12
Probability for LCF Cracks to Initiate at Increments of Steady Stress vs. Start-Stop Cycles

	Stress				
Cycles	**60 ksi**	**70 ksi**	**80 ksi**	**90 ksi**	**100 ksi**
	414 MPa	**483 MPa**	**552 MPa**	**620 MPa**	**690 MPa**
100				2.90E-13	1.17E-10
200	3.41E-15	3.64E-13	2.27E-11	7.26E-09	1.29E-06
300	3.03E-13	4.81E-11	4.10E-09	9.32E-07	9.05E-05
400	5.95E-12	1.15E-09	1.10E-07	1.82E-05	1.09E-03
500	5.32E-11	1.14E-08	1.13E-06	1.39E-04	5.57E-03
600	2.95E-10	6.68E-08	6.50E-06	6.20E-04	1.75E-02
700	1.19E-09	2.76E-07	2.58E-05	1.94E-03	4.06E-02
800	3.84E-09	8.94E-07	7.92E-05	4.78E-03	7.65E-02
900	1.05E-08	2.41E-06	2.01E-04	9.90E-03	1.25E-01
1000	2.50E-08	5.67E-06	4.41E-04	1.80E-02	1.83E-01
1100	5.39E-08	1.19E-05	8.66E-04	2.97E-02	2.49E-01
1200	1.07E-07	2.30E-05	1.56E-03	4.53E-02	3.18E-01
1300	1.98E-07	4.14E-05	2.60E-03	6.50E-02	3.88E-01
1400	3.47E-07	7.10E-05	4.10E-03	8.85E-02	4.57E-01
1500	5.79E-07	1.13E-04	6.13E-03	1.16E-01	5.22E-01

4.6.3.3. Tolerance to Crack Growth Under LCF (Exclusively)

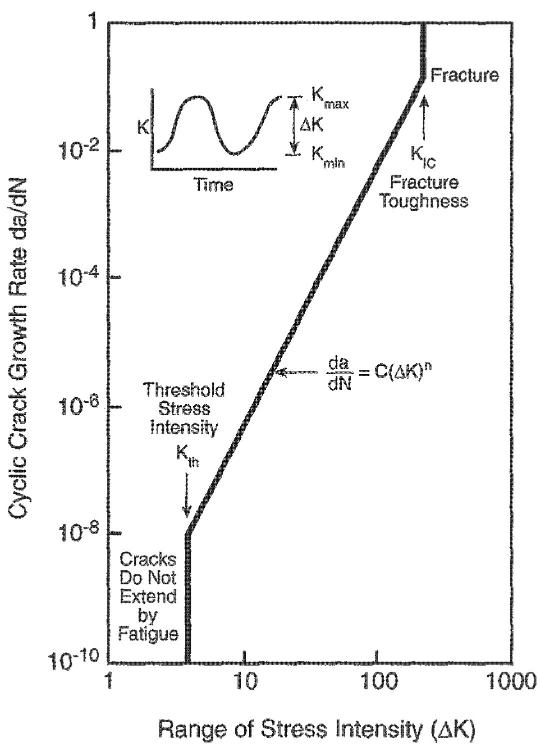
If NDE measurements have actually documented indications that are measurable, Table 4-13 provides a quick estimate of crack growth that might be expected with each successive start-stop cycle of the unit, that is, how much damage might be caused each time the unit is further cycled. This is based on the magnitude of stress calculated for different regions of the blade. It is not meant to represent a precise number. As illustrated in Figure 4-17, the growth rate reflected in the table is estimated from a simplified closed form solution where an idealized loading for the crack configuration was employed. A different correction factor was used to adapt the formula for different stress-regions, shown in Figure 4-18.

The growth rates shown in Table 4-13 should be viewed with a degree of conservatism. In fact, the actual stress intensity will change as the crack moves away from the edge. The purpose of the growth rates is to provide a way to estimate how many start-stop cycles might be tolerated if cracks are discovered or suspected in the component and if the operator is considering a limited period of operation before making repairs. As noted in Section 4.2, before a crack ruptures under the influence of steady stress, the dynamic stress present from vibration will assume control of the propagation process. Therefore dynamic stress ultimately dictates the size of an "allowable" crack, and the engineer is referred to the Section 4.6.4 on HCF where crack limits are provided in Table 4-16.

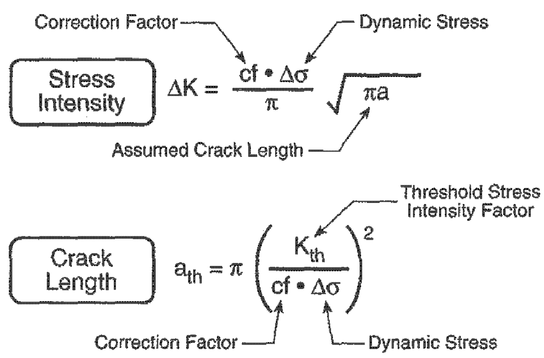
Table 4-13
Estimated Crack Growth Rate (Exclusive to LCF)

Threshold Value (K_{th}): 3 ksi-in$^{1/2}$ (3.3 MPa-m$^{1/2}$) Assumed Existing Crack: 030" (0.762 mm)	Max. Principal Steady Stress		Free Edge Factor	Stress Intensity (ΔK)		da/dN from LCF (per cycle)	
	ksi	MPa		ksi-in$^{1/2}$	MPa-in$^{1/2}$	Inches	mm
Cover	28.4	196.0	10.6	29.34	32.24	4.51E-06	1.15E-04
Tenon	40.9	281.7	2.4	9.58	10.53	1.63E-07	4.14E-06
Airfoil – Leading Edge	25.0	172.4	3.5	8.60	9.45	1.12E-07	2.85E-06
Airfoil – Trailing Edge	28.1	193.7	3.5	9.67	10.62	1.68E-07	4.27E-06
Blade Root	38.9	268.0	2.4	9.12	10.02	1.38E-07	3.50E-06
Disk Attachment	34.2	235.9	2.4	8.02	8.82	8.68E-08	2.21E-06

Example of da/dN Curve



Paris Formulation



ΔK for Different Materials

Material Type	Stress Intensity (ΔK) ksi-in$^{1/2}$	Stress Intensity (ΔK) MPa-m$^{1/2}$
AISI 403	3.0	3.3
AISI 410	3.0	3.3
17-4 PH	5.0	5.5
Ti-6Al-4V	5.5	6.1
AISI 422	3.1	3.4
CH-60	3.1	3.4

Figure 4-17
Nomenclature for da/dN and Paris Formulation

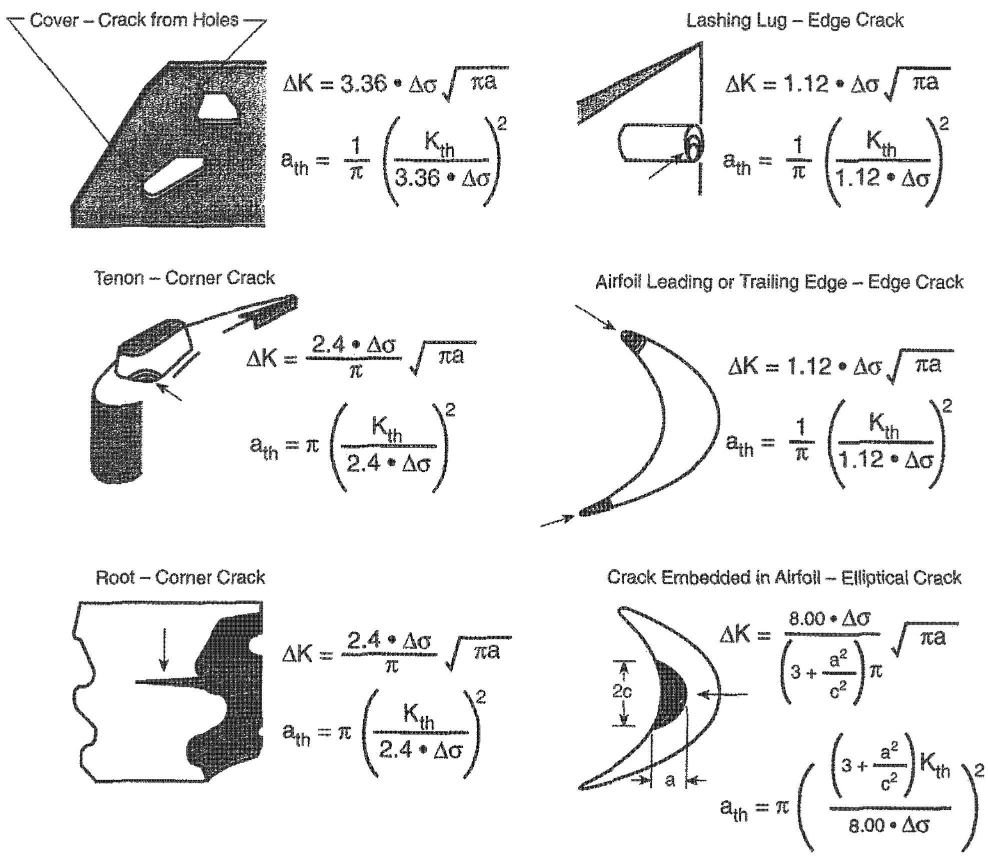


Figure 4-18
Suggested Correction Factors for Different Crack Locations

4.6.4 High-Cycle Fatigue

High-cycle fatigue resistance is assessed primarily as the consequence of total hours operation under the influence of dynamic (vibratory) stress, superimposed on a mean (steady) stress. Blade failure is defined as the number of cycles when cracks are predicted to initiate. As mentioned, for control stage blades, the dynamic stresses used to predict the initiation of HCF cracks are based on an assumed worst case condition of partial arc operation corresponding to 30% of full load.

4.6.4.1 Resistance to HCF

Table 4-14 shows the estimated operating time before cracks are predicted to occur at different regions of a blade under partial arc operation. Maximum dynamic stress is selected from Table 4-10. As with LCF, the original elastic stress results are converted to a mean stress (using Neuber's method and the material properties previously identified) to estimate the amount of plastic strain that would occur during hours of operation and the number of cycles that would be expected to produce an HCF crack commensurate with this magnitude of plastic strain.

Table 4-14 identifies where this blade is more sensitive to HCF during partial arc operation and for which mode of vibration.

Table 4-14
Estimated HCF Initiation Life for Modes Under Partial Arc Operation

Location	Mode	Steady Stress		Max Dynamic Stress		Crack Initiation (Years)
		ksi	MPa	ksi	MPa	
Cover	D	30.7	211.3	0.1	0.7	7.95E+19
Tenon	D	37.4	257.9	0.6	3.8	7.79E+12
Airfoil – Leading Edge	A	21.0	144.8	0.1	0.8	1.68E+21
Airfoil – Trailing Edge	D	23.6	162.7	0.9	5.9	2.30E+11
Blade Root	D	43.0	296.2	1.0	6.8	1.13E+10
Disk Attachment	D	35.6	245.2	0.8	5.4	2.41E+11
Fatigue Strength Coefficient [σ'_f] Applied:				145.8 ksi 1005 MPa		
Fatigue Strength Exponent (*b*) Applied:				-0.094		

4.6.4.2 Probability of HCF Initiation

Table 4-15 and Figure 4-19 present a series of probabilities and curves that reflect the chances of HCF where the mean dynamic stress in the distribution is increased at increments of 1 ksi (6.9 MPa). The probability is derived using a mean stress (40 ksi [275.8 MPa]) throughout a history of cumulative hours.

To establish the current possibility HCF using these data, the maintenance engineer must reference the curve to the total hours experienced by the parts based on their cumulative time in **partial arc operation only**. As previously stated, the time spent in normal full arc operation is not expected to generate dynamic stress sufficient to cause significant HCF damage, that is, the probability will fall below the 3 ksi (20.7 MPa) threshold shown in both the table and graph. The increased possibility for HCF cracks to develop before the next inspection interval is determined by projecting the number of hours that the unit is likely to accumulate before that time.

Table 4-15
Probability for HCF Cracks to Initiate at Increments of Dynamic Stress

		Dynamic Stress Imposed on a Mean Steady Stress of 40 ksi (279 MPa)					
		3 ksi	4 ksi	5 ksi	6 ksi	7 ksi	8 ksi
Years	Hours	21 MPa	28 MPa	35 MPa	42 MPa	49 MPa	56 MPa
1	8,760	3.40E-05	2.90E-04	1.56E-03	5.08E-03	1.06E-02	2.55E-02
2	17,520	5.00E-05	4.40E-04	2.28E-03	6.80E-03	1.45E-02	3.27E-02
3	26,280	6.40E-05	5.36E-04	2.72E-03	8.28E-03	1.71E-02	3.78E-02
4	35,040	7.20E-05	6.34E-04	3.02E-03	9.44E-03	1.90E-02	4.14E-02
5	43,800	8.00E-05	6.98E-04	3.38E-03	1.01E-02	2.08E-02	4.38E-02
6	52,560	8.80E-05	7.74E-04	3.59E-03	1.09E-02	2.22E-02	4.65E-02
7	61,320	9.60E-05	8.34E-04	3.81E-03	1.14E-02	2.37E-02	4.88E-02
8	70,080	9.80E-05	8.86E-04	3.98E-03	1.20E-02	2.48E-02	5.07E-02
9	78,840	1.02E-04	9.30E-04	4.17E-03	1.25E-02	2.61E-02	5.21E-02
10	87,600	1.08E-04	9.80E-04	4.34E-03	1.31E-02	2.70E-02	5.39E-02
11	96,360	1.16E-04	1.02E-03	4.52E-03	1.38E-02	2.79E-02	5.54E-02
12	105,120	1.20E-04	1.08E-03	4.71E-03	1.43E-02	2.89E-02	5.65E-02
13	113,880	1.20E-04	1.13E-03	4.81E-03	1.46E-02	2.97E-02	5.77E-02
14	122,640	1.22E-04	1.17E-03	5.01E-03	1.50E-02	3.04E-02	5.91E-02
15	131,400	1.30E-04	1.15E-03	5.18E-03	1.54E-02	3.12E-02	6.04E-02

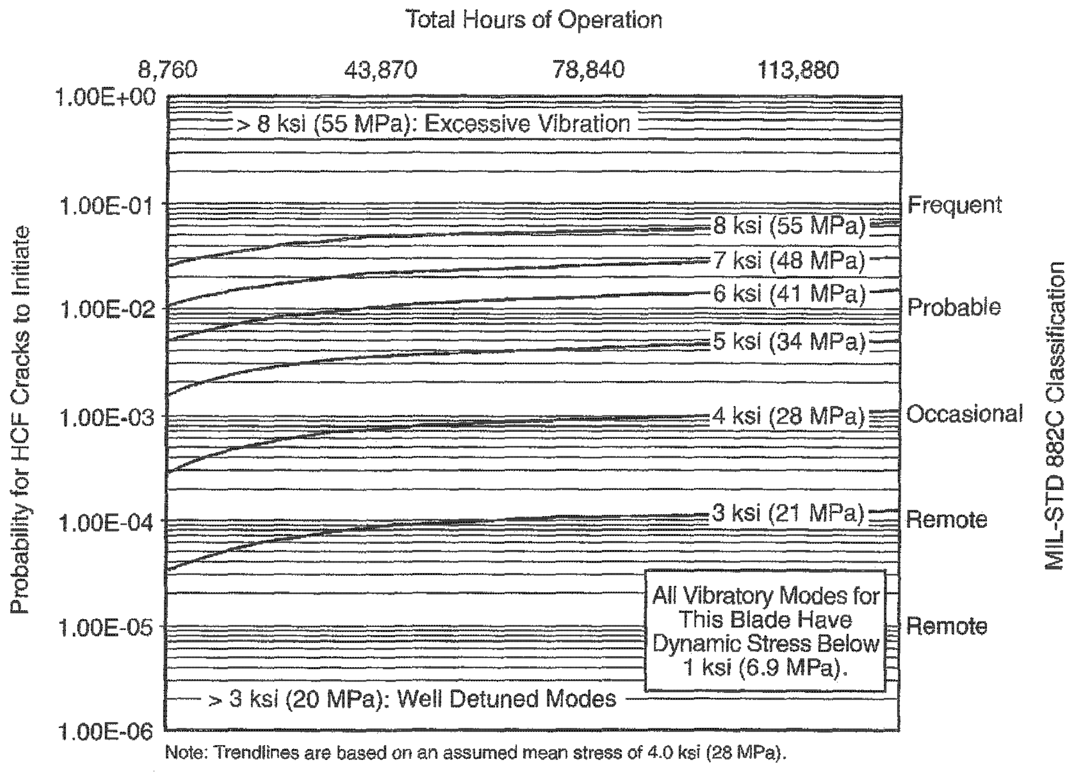


Figure 4-19
Probability of HCF Cracks at Different Levels of Dynamic Stress

4.6.4.3 Tolerance to Crack Growth Under HCF (Exclusively)

As discussed in the previous information on LCF, turbine blades are distinctive in that useful life is generally ended at the point where HCF takes control of the growth process. On a typical da/dN curve of any material, this is when the stress intensity range along the crack front achieves a threshold value of ΔK_{th} previously illustrated in Figure 4-18.

Table 4-16 provides a quick estimate of the approximate size or limit of any crack that might be tolerated within each respective region of the component if the fundamental modes stay detuned, while maintaining the dynamic stress to the levels shown in the table. Any crack approaching this limit places the blade in jeopardy of failing. If the length of an initial crack or indication is known, the number of start-stop cycles to reach the limit set by the point where HCF takes over can be roughly estimated by using the growth rates shown in Table 4-13. It is recommended that any such estimate should include a safety factor of at least 10 to account for the many uncertainties not addressed in this process.

Table 4-16
Estimated Tolerable Crack Size (When HCF Takes Over)

Threshold Value (K_{th}) : 3 ksi-in$^{1/2}$ (3.3 MPa-m$^{1/2}$)	Dynamic Stress*		ND Mode	Free Edge Factor	Allowable Crack (a_{th})	
	ksi	MPa			Inches	mm
Cover	0.12	0.80	D/B	10.6	0.36	9.22
Tenon	0.55	3.81	D	2.4	4.72	119.8
Airfoil – Leading Edge	0.30	2.07	A	3.5	6.96	176.7
Airfoil – Trailing Edge	0.86	5.92	D	3.5	5.51	139.9
Blade Root	0.98	6.77	D	2.4	3.58	90.8
Disk Attachment	0.78	5.35	D	2.4	5.22	132.6
*Highest Dynamic Stress from Table 4-10						

The crack lengths were based on a ΔK_{th} assumed for the blade material, which is the maximum (detuned) dynamic stress selected from one of the four fundamental modes previously examined, and estimated by a closed form solution where an idealized loading is adopted. A different free edge factor is used to adapt the formula for different components of the blade. Again, it should be emphasized that these estimates are to assist the engineer in making inspection-based decisions, for example, estimating how far a crack might propagate before the risk of an in-service failure is very likely. It should be noted that the results associated with estimating crack tolerances are not presented to suggest absolute remaining life predictions. They serve to show the relative tolerance to cracks between different regions of the blades based on the calculated stresses.

The maintenance engineer should also consider regions of higher stress intensity or smaller crack tolerance as principal areas on which to focus inspection and remedial action. In these regions, grinding or polishing might be considered to remove nominal surface damage.

4.6.5 Creep Rupture

Creep rupture is assessed primarily as the consequence of years of operating under the influence of steady (centrifugal) stress in a high-temperature environment. Blade failure is defined as the point where cracks are predicted reach the threshold size or length where dynamic stress and HCF will take control and propagate them to failure.

4.6.5.1 Probability of Failure Due to Creep

To assess the risks of a creep failure (given the stress field of this component), Table 4-17 presents a series of curves (Figure 4-20) that shows the probability of a creep rupture failure for increasing increments of stress versus years of cumulative operating service. The probabilities for creep rupture to occur are based on the material properties of 422 SS at 975°F (524°C).

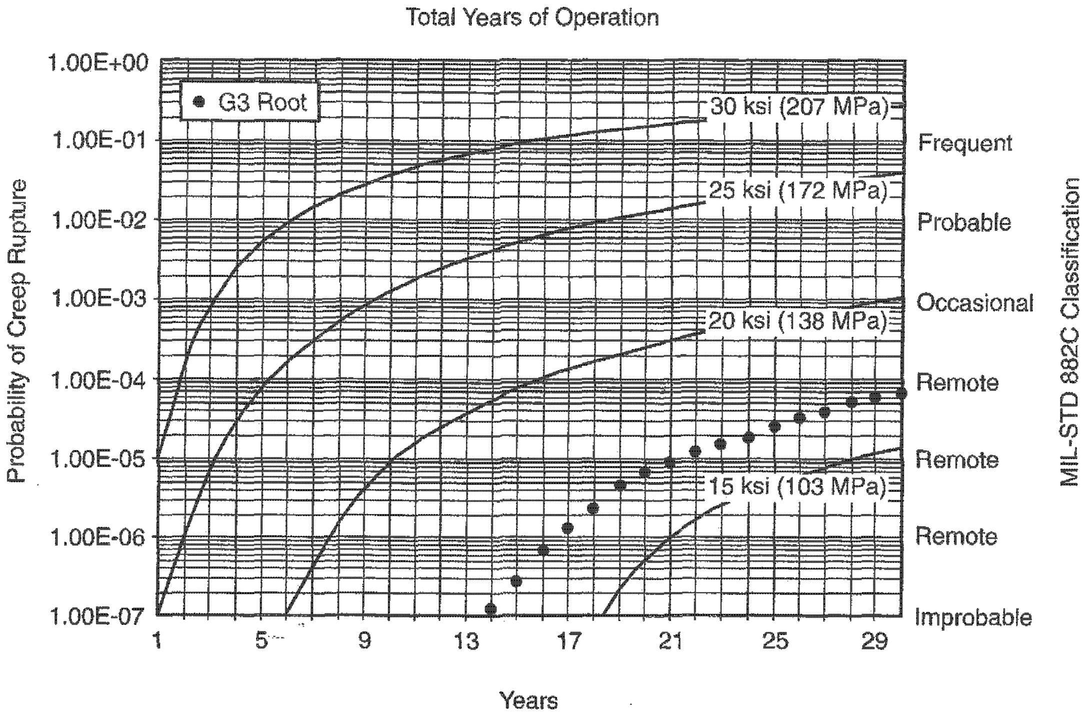


Figure 4-20
Probability of Failure Due to Creep Rupture

Table 4-17
Probability for Failure by Creep over a 30-Year Period

Year	10 ksi	15 ksi	20 ksi	25 ksi	30 ksi	35 ksi
	69 MPa	103 MPa	138 MPa	172 MPa	207 MPa	241 MPa
1					1.00E-05	9.20E-04
2				1.00E-06	1.66E-04	8.13E-03
3				8.51E-06	8.40E-04	2.88E-02
4				3.00E-05	2.51E-03	5.50E-02
5				7.24E-05	5.33E-03	9.00E-02
6			1.12E-07	1.51E-04	9.18E-03	1.27E-01
7			4.00E-07	3.09E-04	1.40E-02	1.65E-01
8			1.48E-06	5.37E-04	2.09E-02	2.03E-01
9			4.07E-06	8.51E-04	2.80E-02	2.42E-01
10			9.12E-06	1.30E-03	3.60E-02	2.78E-01
11			1.55E-05	1.84E-03	4.50E-02	3.15E-01
12			2.57E-05	2.51E-03	5.50E-02	3.49E-01
13			3.72E-05	3.28E-03	6.60E-02	3.83E-01
14			5.13E-05	4.37E-03	7.80E-02	4.14E-01
15			7.24E-05	5.50E-03	8.90E-02	4.42E-01
16			9.55E-05	6.61E-03	1.00E-01	4.70E-01
17		2.00E-08	1.17E-04	7.76E-03	1.12E-01	4.97E-01
18		6.17E-08	1.55E-04	9.12E-03	1.25E-01	5.22E-01
19		1.66E-07	1.91E-04	1.05E-02	1.37E-01	5.46E-01
20		4.57E-07	2.34E-04	1.20E-02	1.49E-01	5.67E-01
21		9.77E-07	2.82E-04	1.40E-02	1.62E-01	5.89E-01
22		1.66E-06	3.39E-04	1.58E-02	1.75E-01	6.09E-01
23		2.51E-06	4.07E-04	1.80E-02	1.88E-01	6.27E-01
24		3.47E-06	4.68E-04	2.09E-02	2.00E-01	6.45E-01
25		4.79E-06	5.50E-04	2.30E-02	2.13E-01	6.62E-01
26		6.17E-06	6.03E-04	2.50E-02	2.25E-01	6.77E-01
27		7.59E-06	6.92E-04	2.88E-02	2.38E-01	6.93E-01
28		9.55E-06	7.94E-04	3.16E-02	2.51E-01	7.07E-01
29		1.15E-05	8.91E-04	3.47E-02	2.63E-01	7.21E-01
30		1.35E-05	9.77E-04	3.72E-02	2.75E-01	7.33E-01

As with the previous plots associated with LCF and HCF, the maintenance engineer must select the curve or curves that are representative of what is anticipated or has been detected in the stage. To illustrate this, the probability of failure for the most highly stressed region of this component is included on the previous plot. The curves shown in Figure 4-20 bounding these data points would represent the range of probabilities governing this set of data as shown in Table 4-17. The increased possibility for a failure from creep rupture before the next inspection interval is determined by moving along the curves for the projected number of years that the unit is likely to run before the next inspection interval.

4.6.6 SPE Damage Tolerance

To account for SPE damage that might be revealed from an inspection of these rows, a family of curves is provided that reflects the increase or decrease in probability for incremental changes in observed damage. The probability of failure is projected over a 20-year interval. The curves are to support a quick assessment of whether the amount of damage observed on either the leading or trailing edge of the airfoil during an inspection presents an unacceptable risk for an in-service failure.

4.6.6.1 Erosion Versus Cracking

Erosion is defined as the formation of a notch on either the leading or trailing edge as shown in Figure 4-21 (a). It is important to note that the appearance of a crack like the one shown in Figure 4-21 (b) signifies a blade that must be either replaced or repaired by completely grinding out the crack. The probability of an in-service failure should be considered unacceptable once a crack as shown in Figure 4-21 (b) is formed at the end of the notch. The probabilistic analysis discussed in the remainder of this section evaluates the potential of reaching this unacceptable condition. It projects the probability that the dynamic stresses will result in the formation and propagation of a crack by means of HCF, based on the rate at which a notch in the leading or trailing edge is being enlarged by SPE.

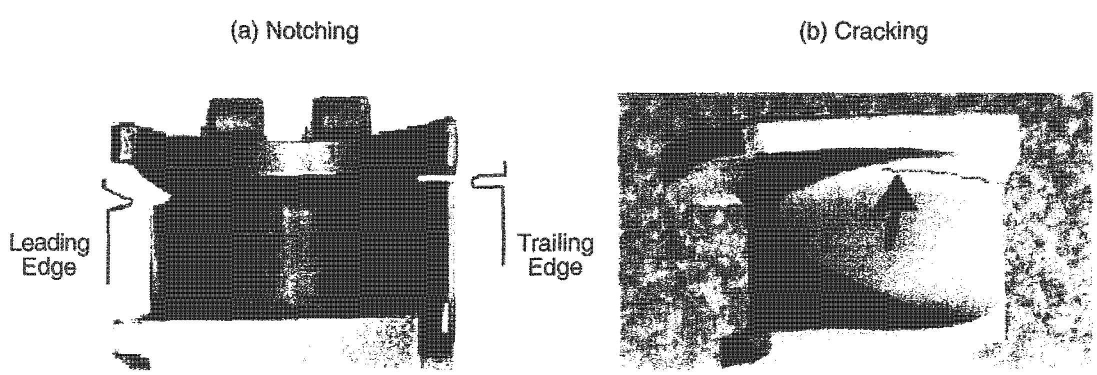


Figure 4-21
Conditional (a) and Unacceptable (b) Forms of SPE Damage

4.6.6.2 Assumptions

The probabilistic treatment of SPE assumes that (during full arc operation and at or close to full load) the flow field is relatively even and the higher-order harmonic stimuli, which excite the control stage blades, are low. For the purpose of evaluating the probability of an in-service failure, the projected probabilities are, therefore, applicable to those periods when a damaged row would be exposed to its most extreme stresses, that is, during partial arc operation.

In this analysis, stress is coupled with a Monte Carlo simulation to determine the stress intensity factors for a given record of SPE. Erosion rate is further based on a statistical treatment of the damage that characterizes the wear pattern around the row. For the purpose of establishing a baseline of inspection curves, a wear pattern or distribution of notch sizes ranging between 50–350 mils (1.27–3.81 mm) was assumed to have resulted after six years of operation. The notch locations and sizes were selected at random. It should be noted that if the same erosion damage occurred in less than the six-year interval assumed in the baseline case, the resulting probabilities would be higher than those shown for each notch increment. Conversely, if the cumulative damage occurred over a longer period of time, the resulting probabilities would be lower than those shown for each notch increment.

4.6.6.3 Results

The probability of failure for blades with damage to either the leading or trailing edge of the blade is shown in Figure 4-22. Within each plot, two series of curves are presented. The dotted line represents the probabilities associated with SPE damage on the trailing edge; the solid line represents damage to the leading edge. Each series of curves represents the change in probability for notches of different sizes, increased by increments of 50 mils (1.27 mm).

To apply these curves, the operator should locate the pair that bounds the depth of the maximum erosion measured from the blades, and then use this pair to establish the relative probability of a failure for future projected service. An example is shown in Figure 4-23, where a maximum erosion depth of 175 mils (4.445 mm) that was found on the leading edge after six years is projected to the end of the next interval (for example, 12 years) to reflect the chances of a failure.

As previously noted, for any analysis of specific SPE damage, actual field measurements can be adjusted to reflect the duration (in years) since the damage occurred. This would allow the probabilistic model to account for a change in SPE rate that might occur as the airfoil profile is changed by erosion, the particle impact angle is increased, and as a consequence, the subsequent material loss is reduced.

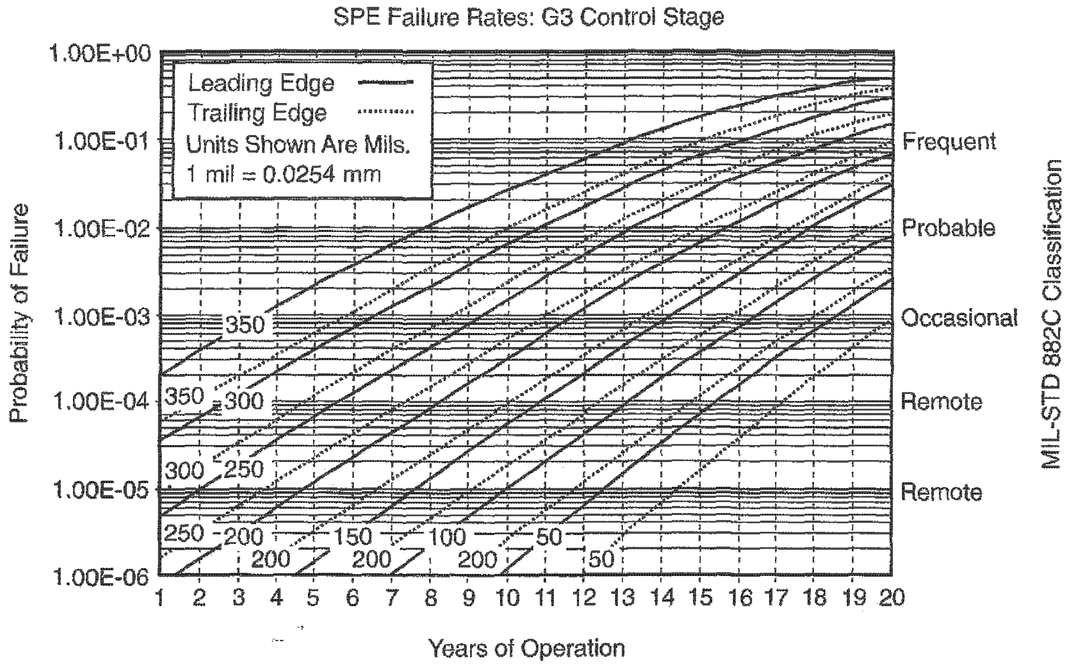


Figure 4-22
Probability of Failure Due to SPE Damage (at Partial Load Operation)

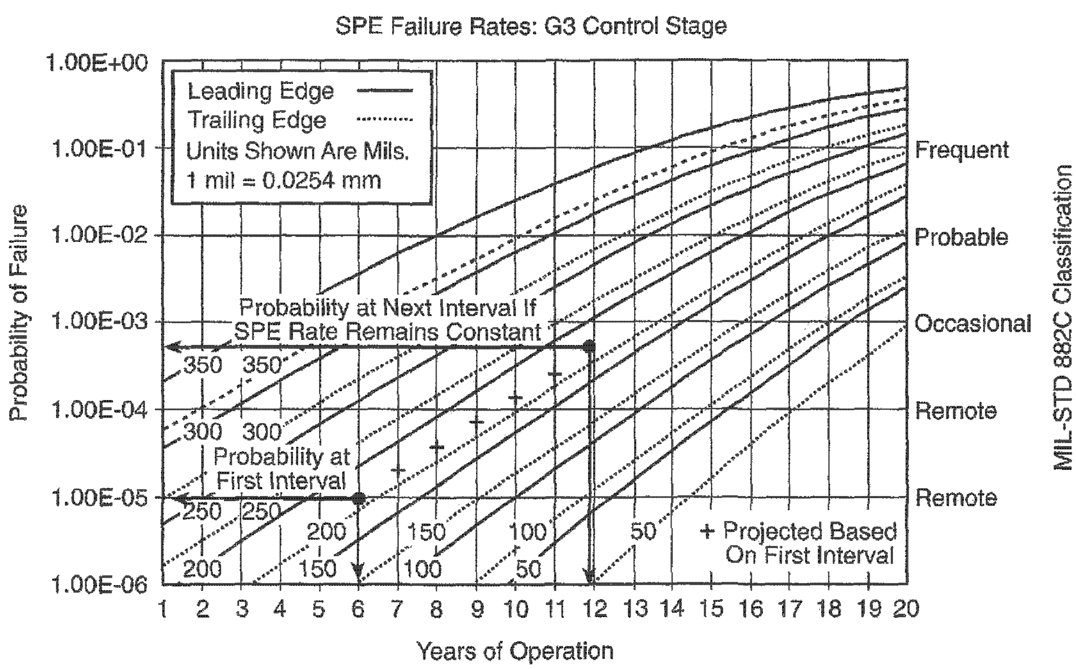


Figure 4-23
Example of Projecting Recorded SPE Damage to the Next Interval

MECHANICAL DYNAMICS and ANALYSIS, LTD

29 British American Blvd., Latham, NY 12110 (518) 399-3616
FAX: (518) 399-3929

BUDGET ESTIMATE 70458-B / 70459-B

SUBMITTED TO:

INTERMOUNTAIN POWER AGENCY

DELTA, UNITS 1 & 2

SUBMITTED:

FEBRUARY 6, 2008

IP7017920

MECHANICAL
DYNAMICS
and
ANALYSIS, LTD

MECHANICAL DYNAMICS & ANALYSIS, LTD.
29 BRITISH AMERICAN BLVD., LATHAM, NEW YORK 12110
PHONE: (518) 399-3616 FAX: (518) 399-3929

www.MDAturbines.com

February 6, 2008

BUDGET ESTIMATE 70458-B / 70459-B
Via e-mail

Intermountain Power Agency
850 W Brush Wellman Rd.
Delta, Utah 84624

Attention: Brad Thompson
Outage Planner

Phone: (435) 864-4414
E-Mail: BRAD-T@ipsc.com

Re: ***Units 1 & 2 CCB Installations – April, 2010 & 2011***

Mr. Thompson:

In response to your request via e-mail Mechanical Dynamics & Analysis is pleased to offer the attached Budgetary Estimate for performing the removal and installation of new Hitachi Continuously Covered Blade designs for:

- Purchase of twelve (12) rows of 30" L-0 Continuously Covered Blades (CCB)
- Installation of six (6) rows and low speed rotor balance for multiple LP sections

The work will be completed on-site over the course of two planned outages scheduled for April 2010 and 2011, respectively. MD&A understands the units are GE S2 machines rated originally at 820 Mw with commercial operation beginning in 1986 and 1987, respectively.

MD&A's proposal is organized as follows:

Section 1 – **Pricing**
Pricing, Scope Description and Schedule
MD&A Rate and Rental Schedules

Section 2 – **Technical**
Technical Clarifications
CCB Promotional Material

Section 3 – **Commercial**
Commercial Clarifications
Insurance Certificate - Sample

MD&A appreciates having this opportunity to serve Intermountain Power, and if we get the order, it will be completed in a highly professional manner.

Best regards,

Leo Molina
General Manager- Steam Turbine Retrofits

Cc: ***MD&A*** - D Hatcher, A.C. Adam, J Reville, H. Miles, R.C. Allen

Section 1 – Pricing

Pricing, Scope Description & Schedule
MD&A Rate and Rental Schedules

Pricing, Scope Description & Schedule

On-Site Replacement of (12) Rows of L-0 Buckets:

The Proposal includes removal and replacement of the existing buckets with Hitachi Continuously Covered Blades (CCB). The work would be performed on-site at the Delta, UT station. Low speed balance included

Prices & Delivery:

L-0 30" Continuously Covered Hitachi Blades Installed:

Included On-Site Scope of Work:

1. **Purchase (12) Rows of 30" CCB's for Delivery January, 2010 and Install Six (6) Rows per Outage (April, 2010 & April 2011):**
   Work scope for each LP section outage: Remove six (6) rows of existing 30" last stage buckets and pins by conventional methods using peening guns and up to 15% of the pins via shooting the pins with Hilti guns, installation of new Hitachi 30" CCB's and LP rotor low speed balance.

   a.

Installation Date	Price
April, 2010 – U1 LPA, LPB, LPC	$5,885,605
April, 2011 – U2 LPA, LPB, LPC	$5,885,605
Total Price	**$11,771,210**

   b. Planned Cycle Time for each Project: 33-35 work-days

   Includes 4 days cleaning & NDE after pin removal

Notes:

- **Prices shown are contingent upon purchase of all (12) rows from MD&A/Hitachi and installation by MD&A personnel.**
- **Prices include 88 blades per row plus a maximum of two extra blades for each end and 264 pins plus a maximum of 100 extra pins/row.** 3 pins/blade
- **Un-used extra buckets and extra pins will remain the property of MD&A/Hitachi.**
- **Sizing of the existing blade dovetail pins is to be confirmed at the time of order.**

Most of MD&A's recent finger dovetail installations have not required the shooting of more than 15% of the pins, and required drilling of less than 6 pins per row. MD&A notes, however, that our past success does not guarantee future results. Occasionally a row or rotor is encountered where the pins are difficult to remove as was recently encountered on a unit with saltwater condensers.

Shooting of dovetail pins beyond 15% with a Hilti gun and drilling of pins would be charged as an extra as follows:

Hilti Gun pin removal $185 / per pin; Removal of pins via drilling $650 / per pin

1. We assumed cleaning and NDE of the wheel dovetails after bucket removal would be performed by an Intermountain Contractor(s) already on-site, therefore, costs for these activities are NOT included in our pricing. Our Planned Cycle Time includes 4-days for the blast cleaning and NDE of the rotors performed by others. *
2. Price assumes that all L-0 dovetail pins can be removed by conventional removal using peening guns plus shooting up to 15% of the pins using the Hilti guns. Any machining to remove the buckets will be considered an extra.
3. Bucket removal, wheel dovetail inspection, installation and final machining will be super-

vised by a MD&A Steampath Engineer. All of MD&A's Steampath Engineers are OEM trained and have a minimum of 20-years of turbine-generator experience

4. Low speed balance of the rotors includes a balance machine, Balance technician and supervision of a MD&A Balance Engineer.

Hitachi CCB Delivery:

Hitachi is manufacturing L-0 Continuously Covered Buckets (CCB's) for stock, owner replacement purchases as well as new units all of the time. Typical delivery from receipt of order is 12 to 14 months.

Advantages of Hitachi 30" L-0 Continuously Covered Blades (CCB's)

As noted, the new 30" CCB L-0 buckets which is identical to the 33.5" CCB except, of course, for vane length and pins will be supplied by Hitachi which has designed and manufactured GE design turbines for over 30 years. This includes the manufacture of 30" L-0 DFLP turbine rotors and buckets of the type currently installed at Intermountain Power. Double flow

The Hitachi CCB L-0 buckets, first installed in 1991 and currently with over two hundred thirty (230) rows in service, have numerous advantages:

The Hitachi 30" CCB offers several distinct advantages which improve reliability:

- Mono-Block blade design *eliminates* the separate side-entry covers which are thought to be one of the potential sources for recent forced outages due to 30" LSB failures. With its ***integral Interlocking "Z-Lock" cover and mid-span tie-boss*** it *eliminates flaring the tenons and "nubs and sleeves.*
- Virtually eliminates areas where deposits can form thereby making the blade *much less susceptible to stress corrosion cracking (SCC).*
- The re-designed transonic blade profile results in:
  - *Stage efficiency increase of 0.8%*
  - *Ability to operate above 50% load at higher backpressure limits*
    - *Alarm set at 7.5" and Trip set at 9" Hg*
  - *Significantly reduced blade stress levels.*
- The vane design includes an Inconel-welded formed stellite erosion nose on the bucket leading-edge which addresses one of the failure concerns regarding the current "un-shielded" blade design incorporated by the OEM – see the enclosed for descriptions of the Hitachi erosion shield configuration.
- A single bucket can be replaced without having to remove other buckets in the row.

  Thus if a bucket is damaged during unit disassembly, impacted by foreign material during operation or experiences some other operational problem, a bucket can be replaced by knocking out just (6) dovetail pins
- The new Hitachi 30" L-0 CCB's blade offers *excellent vibration characteristics.*

  The design natural frequencies were determined by Hitachi using finite element methods and then the analytical results were confirmed by wheel box testing a row of buckets at running speed. In addition, Hitachi's manufacturing plan includes a single bucket standing vibration test to ensure production rows of buckets do not deviate from the original design. Lastly the blade vibration characteristics has been analyzed by a recognized independent technical group (TTI in Rochester, NY) and determined to be a good replacement for the OEM blades.

- Finally, the CCB designs are *Drop-in replacement* for the existing buckets, with *no modifications* required to the existing wheel dovetails or diaphragms.

As stated above the first row(s) of Hitachi CCB L-0 bucket designs entered service in 1991. There are over (230) rows in service world-wide, including the twenty-seven (27) rows installed by MD&A in North America since May 1999. In addition, Hitachi installed eight (8) rows in eastern Canada in 2004. No operational problems have been reported with any of these installations.

The attached Hitachi CCB literature provides additional information on these benefits. MD&A's Commercial Clarifications, Technical Clarifications and 2007 Published Rate Schedule are also attached. The rate schedule, Commercial and Technical Clarifications in effect at the time of purchase order placement, will apply.

2008 RATE SCHEDULE

U.S. and CANADA

(01/01/08 THRU 12/31/08)

	Hourly Rates *(Note 2)* S.T.	O.T.
Engineering Rates		
Field Engineer, Technical Field Advisor, Generator Specialist	$ 172.00	$ 258.00
Project Management, Steampath Engineering Supervision	$ 188.00	$ 282.00
Engineering Consultant, Specialty Field Engineer *Controls, Excitation, Balancing, Alignment, Shell/Casing Repair*	$ 234.00	$ 351.00
Principal Engineer	$ 300.00	$ 450.00
Labor Rates		
Steampath Specialist	$ 115.00	$ 172.50
Steampath Work Leader	$ 85.00	$ 127.50
Steampath Technician *Blader, Machinist, Welder, Seal Technician*	$ 78.00	$ 117.00
Generator Technician	$ 110.00	$ 165.00
Craft Labor, Administrative/Clerical	Available upon request	
Equipment, Parts, Services	**Daily**	**Weekly**
Turbine Tool Container *(Note 3)*	$ 900.00	$5,400.00
Purchased/Subcontracted Parts and Services	Cost + 17%	
Steampath Consumables *(Note 4)*	$ 10.00/person/hour	
Turbobalancer	$ 230.00	$1,380.00
Travel and Living Expenses		
Per Diem *(Note 5)*	$ 210.00/person	
Travel Expenses	Cost + 10%	
Personal Vehicle (to and from worksite)	IRS Standard Rate + 10% or $1.20/Mi/Truck	

NOTES:

1. *Rates are based on a minimum or ten (10) hours per day, six (6) days per week per person. Any required stand-by time will be billed at S.T. rates and limited to ten (10) hours per day, six (6) days per week per person.*
2. *O.T. is defined as work over eight (8) hours on weekdays and all hours worked on Saturdays, Sundays, and Holidays.*
3. *Pricing for turbine tool container does not include shipping and freight, which will be invoiced at cost + 10%.*
4. *Rate excludes weld filler materials in some high deposition applications and all silver solder.*
5. *Firm price per diem rate includes local transportation, lodging, meals, laundry, communications and incidentals. Price shown is based on rural to medium suburban areas. Large metropolitan locations (such as NYC, Chicago, Los Angeles, etc.) or locations where seasonal/special event rates apply will be quoted upon request.*

TERMS:

1. *Payment terms – Net 30 days.*
2. *1½% per month finance charge applied to late payments.*
3. *All prices in U.S. Dollars.*
4. *Subject to MD&A TERMS AND CONDITIONS, SALE OF SERVICES AND PARTS (dated 8/1/07).*

2008 MD&A Tool/Equipment Rental Schedule

is available upon request.

MD&A, Ltd., 29 British American Blvd., Latham, NY 12110
Tel: 518-399-3616, Fax: 518-399-3929
WWW.MDATURBINES.COM

Section 2 – Technical

Technical Clarifications
CCB Promotional Material

Technical Clarifications

1. In case of a work stoppage of any nature beyond MD&A's control, we will give the Customer the option of keeping our crew standing by locally or returning our crew to their home base. In the event that crew members are required to return to their respective home base location and to return to the Customer's plant at a later date to finish the work, MD&A will submit a quotation for appropriate "in and out" expenses due to the work stoppage.

2. MD&A assumes no liability for the on-site crane inspection or its operational reliability. It will be the Customer's responsibility to determine that the crane meets all operational and safety standards. The proper operation of the overhead crane is critical to the success of this outage. It is therefore imperative that Customer makes every effort to have a complete preventive maintenance check performed prior to the outage. MD&A does not include a crane inspection. Critical spare parts should also be inventoried and parts' lead times checked with suppliers. We understand that it may be necessary to share the use of the crane with another vendor. Minor delays in crane availability can be accommodated, however extended periods of time during which the crane is not available will be considered delay time. Additional overtime required to regain the schedule will be billed per the Rate Schedules.

3. Delays beyond MD&A's control during the low speed balancing will be extra at a rate of $2500 per day for the balance machine and crew. Customer to provide electrical hookup to 480 volt supply, crane and rigging support to assemble balance machine and set rotor(s).

4. All electrical testing will be performed at the OEM's recommended voltages, unless otherwise instructed by Customer.

5. The conditions of any tests shall be mutually agreed upon and MD&A shall be notified of, and may be represented at, all tests that may be made.

6. Straight time is defined as work up to (8) hours on weekdays. Overtime is defined as work after (8) hours on weekdays and all day Saturday, Sunday holidays.

7. Work durations are calculated based on working ten (10) hours per day, two (2) shifts, seven (7) days per week.

8. Removal of the buckets, wheel dovetail inspection, installation and final machining of the new CCB's will be supervised by a MD&A Steampath Engineer.

9. MD&A will require the Owner to provide the existing dovetail pin sizes at the time of purchase order placement to allow manufacture of the proper sizes and quantities of pins, over-size pins and reamers. If such data is not available, it may be available from old outage reports or it can be obtained through measurement of the pin sizes by accessing the rotor through the LP hood manways. MD&A can perform these measurements on a firm price basis or on a T&M basis using our published rates in effect at the time.

10. The potential for *un-necessary* schedule delays and increased costs associated with difficult pin removal requiring shooting, drilling of pins or machining the buckets off can be avoided by the Owner by ***liberally and continually soaking the L-0 wheel dovetails and pins with Kroil*** as soon as the rotor is accessible. MD&A can not stress this enough – it sounds like a minor issue but difficulty in conventional removal of dovetail pins can result in significant extension of a planned outage.

11. L-0 bucket quantity per row is 88 plus a maximum of (2) extra buckets per row will be provided. In addition, the price includes 264 dovetail pins/row plus a maximum of 100 extra pins/row will be made available during installation work.

12. A maximum of 100 extra pins / row will be made available to MD&A by Hitachi during the installation work. Sizing is to be confirmed by the owner at the time of order. Unused pins remain the property of Hitachi.

13. Unused buckets and pins remain the property of MD&A/Hitachi and must be returned.

14. Manufacturer's inspection prior to shipment shall be final.

15. All installation hardware and tooling is included.

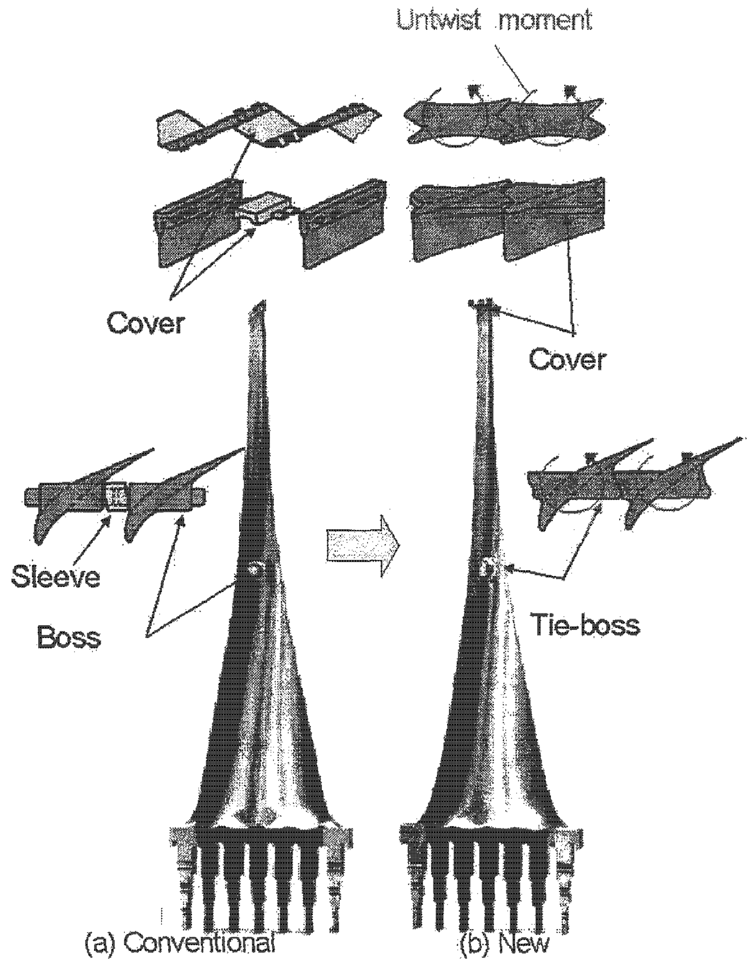
16. Packing will be standard export packing suitable for ocean/air/ground transportation.

17. Pricing includes ocean transport of the buckets and pins. Expedited shipment by air, if required to support a short turnaround delivery or forced outage, is extra and will be added. Air shipment will take approximately 10 days after MD&A/Hitachi are notified.

18. Should the new CCB blades not fit the existing unit MD&A/Hitachi will replace them at the next opportunity. The supplied blades that cannot be fit to the existing unit must be returned to MD&A/Hitachi.

19. As is normal practice on finger dovetail buckets we will attempt to remove the existing buckets in a manner that would allow them to be re-installed and operated until a replacement set can be manufactured. Of course, if normal bucket removal practices are un-successful and before any destructive methods for removal of the existing buckets are implemented the schedule impact, costs and risks will be reviewed with and approved by the Owner.

HITACHI 30" and 33.5" L-0 CCB Blade



Comparison of Old Designs and New CCB Designs

High Reliability:

Forged Blade with Interlocking Integral Cover

Formed Stellite Erosion Shield

Less Susceptibility to SCC

"Drop-In" Replacement:

No Replacement of Diaphragms or Modifications to Existing Parts

Transonic Blade Profile

Slight Stage Efficiency Increase

Improved Backpressure Limitation

Excellent Vibration Characteristics

Independent Review

Stellite Erosion Shield

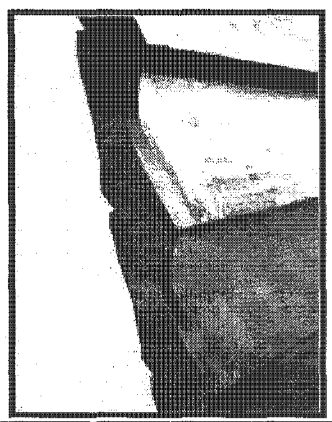
Formed Stellite Nose

TIG Welded-On with Inconel

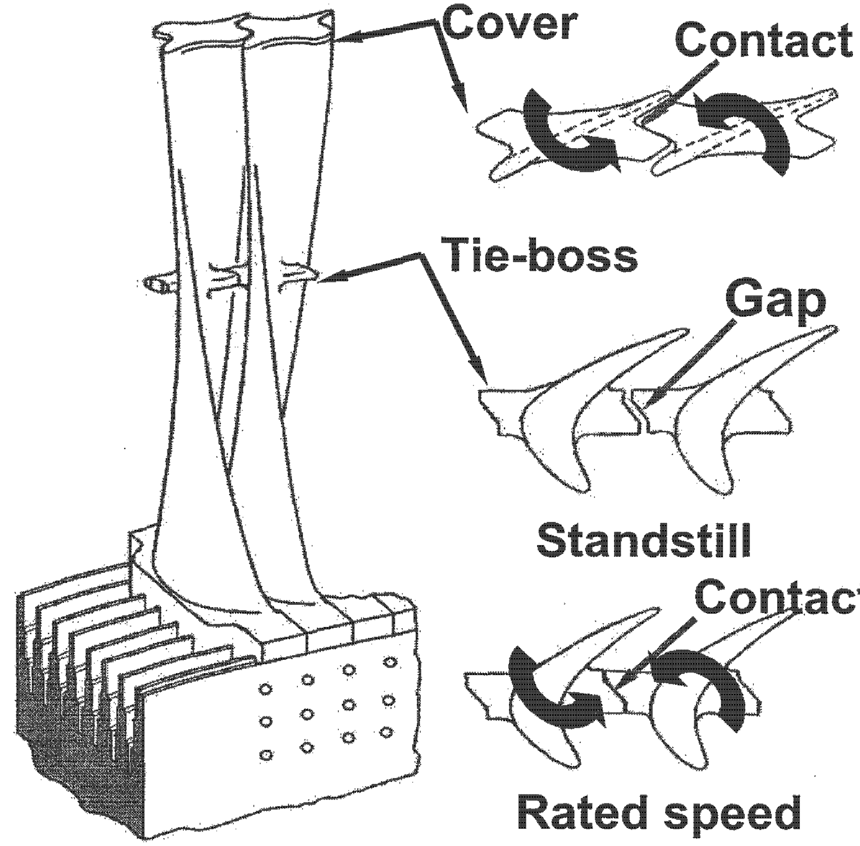
Technology For Turbine Upgrades

□ **CCB Buckets**

-The blade has an integrally formed cover at the blade tip and a continuously coupled structure is adopted by connecting adjacent by the contact of the cover.



Integrally formed cover
(S-form cover)



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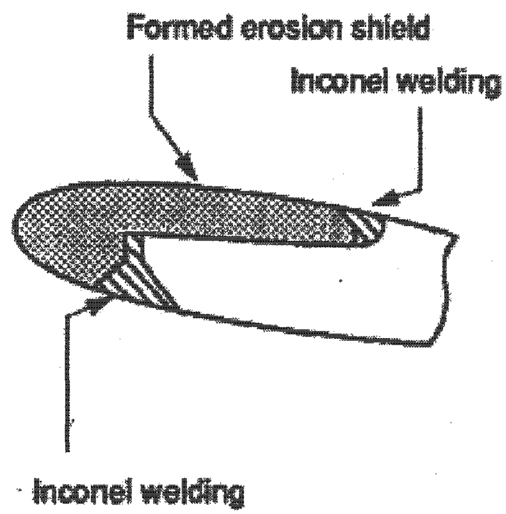
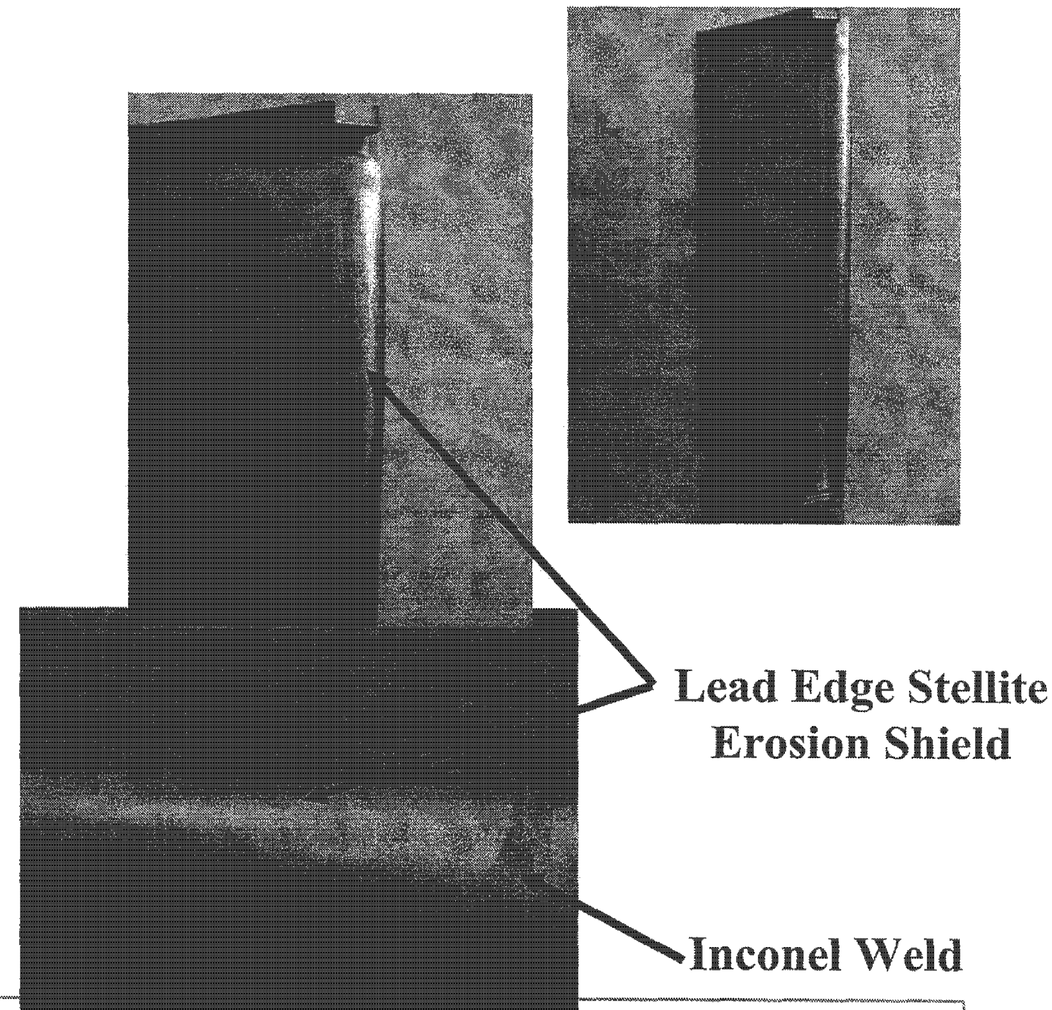
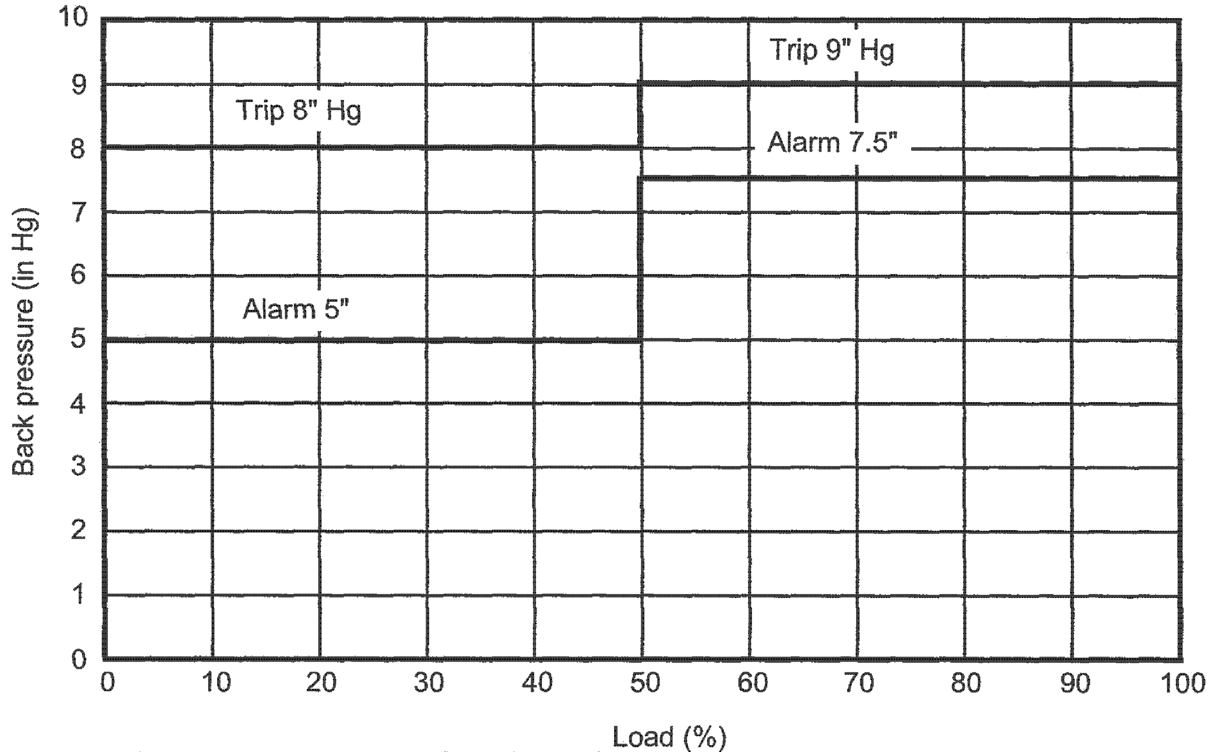
HITACHI 30" and 33.5" L-0 CCB Blade

- **Lead Edge Protection**
  - Stellite Shield
  - Quench Hardened
- **Stellite Erosion Shield**





HITACHI 30" L-0 CCB Blade – Backpressure Limits



Excellent Backpressure Limitation:

Excellent Vibration Characteristics

More Effective Operation by Changed limitation

33.5"CCB Blade

Independent Review

Independent Assessment

of 33.5" CCB L-0 Blade Design

Technical Report PA 48-1.1

Prepared for:

H. Ikeda
Senior Engineer and Section Manager, Turbine Global Services Section
Preventive Maintenance Engineering Center
Hitachi Engineering & Product Division
Power & Industrial Systems, Hitachi Ltd.
3-1-1 Saiwai-cho Hitachi-shi
317-8511 JAPAN

Prepared by:

David VanBronkhorst

Senior Project Engineer
Turbine Technology International

Reviewed by:

Tony Lam
President, Turbine Technology International

April 6, 2000

Turbine Technology International
2024 W. Henrietta Road, Suite 5-F

MECHANICAL DYNAMICS and ANALYSIS, LLC

HITACHI
Inspire the Next

33.5"CCB Blade

Independent Review

9. CONCLUSIONS

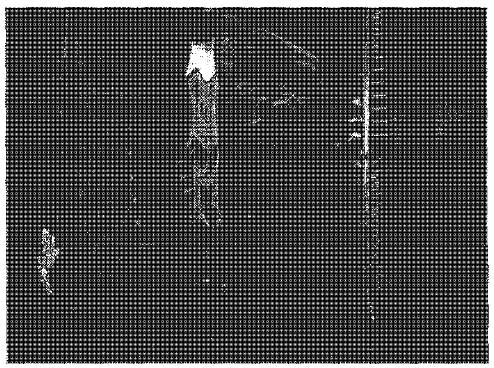
1. The continuous cover band (CCB) design for the 33.5" L-0 stage operates within allowable levels of steady stress. The design also has very good frequency margins of detuning for each of the first four model families. The margins result in levels of dynamic stress that are well below the 3 ksi criteria set by the independent assessment procedure.
2. By using an integral cover, the CCB design is able to eliminate the potential for problems associated with the original L-0 design. The CCB design eliminates the stress concentration in the cover tenon. It eliminates the potential for corrosion attack and SCC in the tenon hole and tie-wire regions. It eliminates the possibility of frequency drifting, which is believed to cause a resonant condition as oxides build up between the interfaces of the airfoil and tie wire.
3. The frequency results of the CCB also indicate that a successful and less complicated detuning strategy can be achieved without the uncertainty and difficulty of a bucket disc mix-tuning strategy. This was achieved by adopting a continuous-tie arrangement around the disc, similar to the long-arc strategy that has also been adopted as a remedial fix.
4. In comparison to the original L-0 designs, the CCB not only eliminates or avoids several issues that are believed to have compromised their reliability over time, but also operates with lower steady stresses and lower dynamic stresses than its counterparts. On a qualitative basis, this provides the CCB design with a greater margin of resistance to LCF damage and a greater tolerance for HCF.
5. Regarding long term reliability, the CCB design is less susceptible to the mechanisms of aging and wear that are unavoidable within the aggressive operating environment of low pressure steam turbine stages that are approximate to or beyond the Wilson line. The CCB design therefore is considered to represent a viable long-term solution to the problems associated with the original 33.5" bucket.

North American CCB Experience

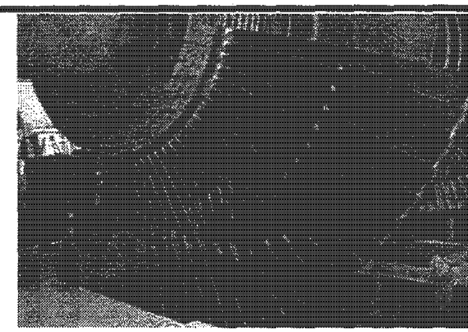
- 54+ Rows Installed In North America
- 26 Rows Installed On GE Units
  - By MD&A
- 40+ Rows On Order

Installations by MD&A Include:

- LG&E, Cane Run 4
- LG&E, Trimble County 1
- APS, Four Corners 1 & 2
- KU, Ghent 1
- Xcel Energy, Highbridge 6
- Alliant, Edgewater 4
- Entergy, Sabine 3
- ATCO Electric, Sheerness
- Tampa Electric, Big Bend 4 (Feb, 2007)



NBP – Coleson Cove Unit No. 3
Hitachi 350 MW Steam Turbine
4 Rows Of 26" L-0 CCB Buckets Installed By MD&A During Turbine Upgrade



Alliant Energy- Edgewater
GE 330 MW Steam Turbine
2 Rows Of 33.5" L-0 CCB Buckets Installed On An Emergency Basis Due To GE Bucket Failure

Hitachi's CCB Experience

CCB Model	Rows In New Units	Rows Re-Bladed	Total	First Operation
26 in L-0 /3600 rpm	28	93	121	1991
26 in L-0 /3000 rpm	10	12	22	1993
30 in L-0 /3600rpm	2	12	14	2004
33.5 in L-0 /3600rpm	4	12	16	2000
33.5 in L-0 /3000 rpm	2	16	18	2002
40 in L-0 /3600 rpm	17	0	17	2002
40 in L-0 /3000rpm	4	0	4	2004
43 in L-0 /3000 rpm	12	0	12	2002
15.9 in L-1 /3000rpm	4	0	4	2003
17 in L-1 /3600	2	0	2	2004
19.4 in L-1 /3000rpm	0	16	16	2003
20.9 in L-1 /3600 rpm	6	10	16	1998
22.5 in L-1 /3600rpm	10	0	10	2005
25 in L-1 /3000rpm	8	0	8	2002

□ Other Developed CCB's
48 in L-0/1800 rpm, 46 in L-0/3600rpm, 34 in L-1/1800 rpm, 16.59 in L-1/3600 rpm, 17.41 in L-1/3600rpm

MD&A's CCB Experience

Date	Customer	Station/Unit	Stages	OEM	Size	Type
May-99	Louisville G&E	Cane Run 4	26" L-0 (2) Rows	GE	175	D5
Nov-02	Louisville G&E	Trimble Cty 1	26" L-0 (4) Rows	GE	512	G2
May-02	Arizona PS	Four Corners 1	26" L-0 (2) Rows	GE	175	D5
Nov-02	Kentucky Utilities	Ghent 2	26" L-0 (4) Rows	GE	511	G2
Feb-03	Xcel Energy	Highbridge 6	26" L-0 (2) Rows	GE	156	D3
Apr-03	Ace Cogen	Trona	26" L-0 (1) Rows	HT	108	SF-26
Aug-03	New Brunswick Electric Power	Coleson Cove 3	26" L-0 (4) Rows	HT	315	TC4F-26
Feb-04	Alliant Energy	Edgewater 4	33.5" L-0 (2) Rows	GE	330	D8
Apr-04	Arizona PS	Four Corners 2	26" L-0 (2) Rows	GE	175	D5
Feb-05	Entergy	Sabine 3	26" L-0 (4) Rows	GE	410	G2
May-05	ATCO Electric	Sheerness	33.5" L-0 (2) Rows	HT	381	TCDF-33.5
Feb-07	Tampa Electric	Big Bend 4	26" L-0 (4) Rows	GE	444	G2

Section 3 – Commercial

Commercial Clarifications
Insurance Certificate - Sample

Commercial Clarifications

1. **Price/Payment**
   a. In the event MD&A is the recipient of an order for LSB bucket replacement with Hitachi CCB's, we propose the following Payment Schedule: 25% with the placement of the orders, 25% upon completion of the buckets, and 50% upon completion of work.
   b. Estimate does not include any site specific training or medical testing.
   c. All invoices net thirty (30). Work permits, customs, duties and taxes, if any, are an extra
   d. If bonding is required, the bond cost allowance is based on known workscope. If contract extras are awarded, all invoices for such extra work will be surcharged to cover additional bond costs.
   e. MD&A reserves the right to change the contract payment terms, including payment in advance or in escrow, if the client's credit rating reduction requires such. If subsequently revised payment terms are not accepted by the client, MD&A reserves the right to withdraw this quotation or cancel the contract, without further MD&A obligations or penalty. MD&A retains ownership of all goods and services performed under this contract until full payment is received.

2. **Extra Work**
   a. MD&A will be reimbursed for purchased services and materials as part of extra scope work, with Customer's prior approval, at invoice price plus fifteen percent (15%), including Subcontractor services, rental equipment and purchased materials (plus applicable transportation charges to jobsite). All extra work performed by MD&A Staff and Labor will be invoiced per the attached MD&A Rate Schedules.
   b. MD&A shall be entitled to appropriate adjustments for any changes requested by Customer from the contract specifications. MD&A shall not be required to comply with any requested change order until Customer and MD&A have reached written agreement on appropriate adjustments in price, schedule, and scope of work.

3. **Validity**
   a. Proposal is valid for ninety (90) days. Extensions may be requested by the Customer.
   b. Due to practical considerations concerning demand for services and scheduling of resources, all offers of services are subject to prior commitment.

4. **Warranty**
   a. MD&A offers a twelve month warranty for defects in materials, workmanship and title, and that the work shall conform to the contract specifications following the unit's return to service, or eighteen months following completion of work, whichever occurs first. Warranty responsibility is limited to the value and workscope of services performed. In the event of any warranty deficiencies, MD&A shall, at its option, repair or replace the defective work and re-perform any associated services. MD&A shall not be responsible for latent defects, normal wear and tear deficiencies or those caused by improper operation or maintenance. The warranties and the warranty remedies set forth shall be Customer's sole and exclusive remedy for defects occurring during the warranty period. MD&A also warrants that parts are free from any infringement of US patents. For equipment which is placed in long term storage prior to installation or startup, the warranty will apply only if MD&A has approved the storage and testing procedures of the equipment.

5. **Liquidated damages**
   a. LD's are not a part of this offer.

6. Insurance/Liability

a. Insurance is offered in the amounts and kinds shown on our insurance certificate, a copy of which is attached.
b. Neither MD&A nor its insurer will agree to waive subrogation rights on any coverage.
c. Indemnification obligations shall only apply to claims by third parties for damage to property or personal injury and shall be limited to the extent of each party's degree of negligence or fault.
d. MD&A's and its subcontractors' aggregate liability under the contract for direct damages, indemnification, guarantees, warranties, and/or otherwise shall be limited to claims which arose prior to the expiration of the warranty period and shall not exceed the price allocable to the portion of the particular part or service giving rise to the claim and must specifically exclude consequential, special, indirect, exemplary, and incidental damages.

7. Title

a. Title to parts shall pass to Customer when services and associated parts have been paid in full.

8. Delays/Cancellation

a. MD&A and Customer to reach a mutually agreeable Cancellation Schedule in the event the Customer elects to terminate any part of the contract for convenience. MD&A shall be entitled to reasonable adjustments in price, schedule, and scope in the event Customer suspends work. MD&A shall be entitled to continue the manufacture of parts and receive contract payments during a suspension and shall store such parts at Customer's expense upon completion of manufacture.
b. MD&A shall not be liable for and shall receive a schedule extension for delays due to events which shall include events beyond MD&A's reasonable control including but not limited to acts of God, acts of Customer, civil unrest, war, terrorist acts, earthquake, acts of governments, acts of other contractors, unavailability of required materials and services, strikes and other labor disturbances. MD&A shall be entitled to reasonable adjustments in contract price for delays caused by Customer or its other contractors.
c. Customer shall be entitled to terminate the contract in the event MD&A fails to commence reasonable cure within 30 days after notice from Customer specifying a material default. MD&A's liability for material default shall be limited to the additional amount Customer must pay a third party to complete the work over what Customer agreed to pay MD&A.

From GE

Specification and Scope of Work
Last Stage Buckets

BACKGROUND.
A proposal is requested for the supply and installation of new Last Stage Buckets (LSB's), on the ________________Low Pressure Turbine Rotor. The Unit #__ Turbine Generator is a GE S-2 model. The LSB's are GE 30", self shielded buckets.

PROPOSAL REQUIREMENTS

- Vendor shall provide a total turn-key project to replace six rows of LSBs and shall include, but not limited to, all NDT prep, NDT, LSB buckets, low speed balancing, and all preliminary dynamic and static analysis.
- The proposal for the replacement LSB's shall be for fabrication from Jethete M-152 material, with hardness of 330 to 350 BN, incorporating a weld-attached stellited nose bar.
- The buckets shall also include larger nub and rocker sleeve, over-twist design with larger tenon hole clearance and larger associated tenon and cover piece.
- The design shall be similar to the Mark IV version, available from GE in the early 1970's.
- Buckets shall be certified and all confirmation of all quality inspections and/or reports to be provided with delivery of buckets.
- Vendor shall describe design criteria and program of analyses, test and operating experience which will be or has been performed to assure the design criteria are met for the ______, Unit __ turbine generator, for torsional and lateral natural frequencies with the new LSBs installed.
- The proposal shall include a complete description of the welding procedure for attaching stellite nose bar to bucket, including nose bar geometry.
- The proposal shall identify costs for replacement dovetail pins. The nominal inner dovetail pinholes are approximately 0.XXX" diameter, the center dovetail pinholes are approximately 0.XX" diameter, and the outer dovetail pinholes are approximately 0.XXX" diameter. All dovetail pins are XX" in length and fabricated from H-11 tool steel.
- Proposal shall include design information of condenser backpressure alarm and trip points, including operation allowances as a function of condenser backpressure.
- Proposal shall include a schedule showing time frame and major milestones for the installation of the last stage buckets.
- Any modification to other turbine components, such as diaphragms, seals, flow guides, etc., may be included as an addendum only. Reasons and value for all modifications shall be explained in the addendum.
- Proposal shall also include the number of existing installations with corresponding years of service of the proposed bucket design.
- Proposal shall include warranty information related to material and workmanship.

SCHEDULE

· torsional frequencies
· lateral frequencies

· dovetail
· pin map

IP7017942

Bidders shall also provide a proposal for installation of LSB's during a scheduled XX-day outage during the months of _________ through ___________, 20__.

- The turbine overhaul contractor shall perform all NDT testing of the rotor bore and LSB dovetails, including preparatory work required by the applicable codes and standards. Vendor shall list all applicable NDT codes and standards as part of their proposal and submit a report including data and recommendations after all work is complete.
- Remove the existing buckets and then install new buckets provided as part of this contract. Afterwards the vendor shall complete a low speed balance on the final assembled rotor.
- It is anticipated that the rotor will be available to successful vendor on ________ __, 20__ and LSB installation, including low speed balance, shall be completed by _________ __, 20__.
- Schedule shall be coordinated and finalized with successful bidder, turbine overhaul contractor and ____________ by ____________ 20__.

Proposed Bucket Design Data
(To be completed by Bidder)
Last Stage Buckets

Manufacturer	
Bucket model name	
Effective length	
Weight per bucket (lb)	
Type of erosion protection	
Method of erosion shield attachment (if applicable)	
Material	
Cover type	
Mid-span support type	
Backpressure alarm	
Backpressure limit (trip)	
Number of rows installed	
Oldest installation using proposed bucket design	
Experience List	(Comprehensive list of all projects for parts and service using proposed buckets)

Low Speed Balance Acceptance Criteria	
Low Speed Balance Plan	
Torsional Frequency Analysis Criteria and Results	
Lateral Frequency Analysis Criteria and Results	

From Turbocare

INTERMOUNTAIN POWER SERVICE CORP.

RFP for Last Stage Blades for IPP LP Rotors

This request is to provide last stage blades for ______. This unit is a GE S2 design with a nominal rating of 820 MW, Serial number ______ with a commercial operation date of ______. The existing blades are originally designed 30" LSB of the continuously coupled tie wire sleeves type. They are manufactured out of a GE type Jethete material and are a self shielded design.

The blades presently in the unit have seen a significant amount of erosion. *See attached photos*. The proposed design should maintain original steam path design, reduce erosion rates, and prolong the life of the blades.

Proposal is due on _______ and the following specifications must be presented in the tables below:

- Design details of the proposed blades including:
    - Mechanical material properties of the blades (primarily tensile strength, hardness and fatigue strength) both of the parent material as well as any shielding
    - Blade shielding type including details on the method of attachment
    - A finite element analysis showing the steady stress analysis of all key features of the blades (cover, tenon, tie-wire, air foil, root, disk attachment) with a summary of the stresses in a format similar to below

Summary of Calculated Steady Stresses (Required)

Structural Feature Material Yield Strength:	Max Equivalent Elastic Stress		Max Principal Elastic Stress		Local Yielding?*	True Stress	
	ksi	MPa	ksi	MPa	Yes or No	ksi	MPa
Tip Linkage							
Tie Wire – Lashing Lug							
Airfoil							
Blade Root							
Pins							
Disk Attachment							

* Yes is indicated if the reported elastic stress exceeds the material yield strength.

- A dynamic analysis of the blade disk frequencies and dynamic stresses both at zero and rated speeds for the first 10 modes, summarized in tabular form similar to below

Blade-Disk Natural Frequencies, for both zero speed and 3600 RPM (Required)

	Frequencies Shown are: __ Calculated __Measured			
Nodal	*Mode Family*			
Diameter	*A*	*B*	*C*	*D*

Resonant Dynamic Stress (Maximum Principal) for ND Mode Families (Required)

Region	Mode A		Mode B		Mode C		Mode D	
	ksi	MPa	ksi	MPa	ksi	MPa	ksi	MPa
Tip Linkage								
Tie Wire – Lashing Lug								
Airfoil								
Blade Root								
Pins								
Disk Attachment								

QA

- The blades should be moment weighted and the documentation provided

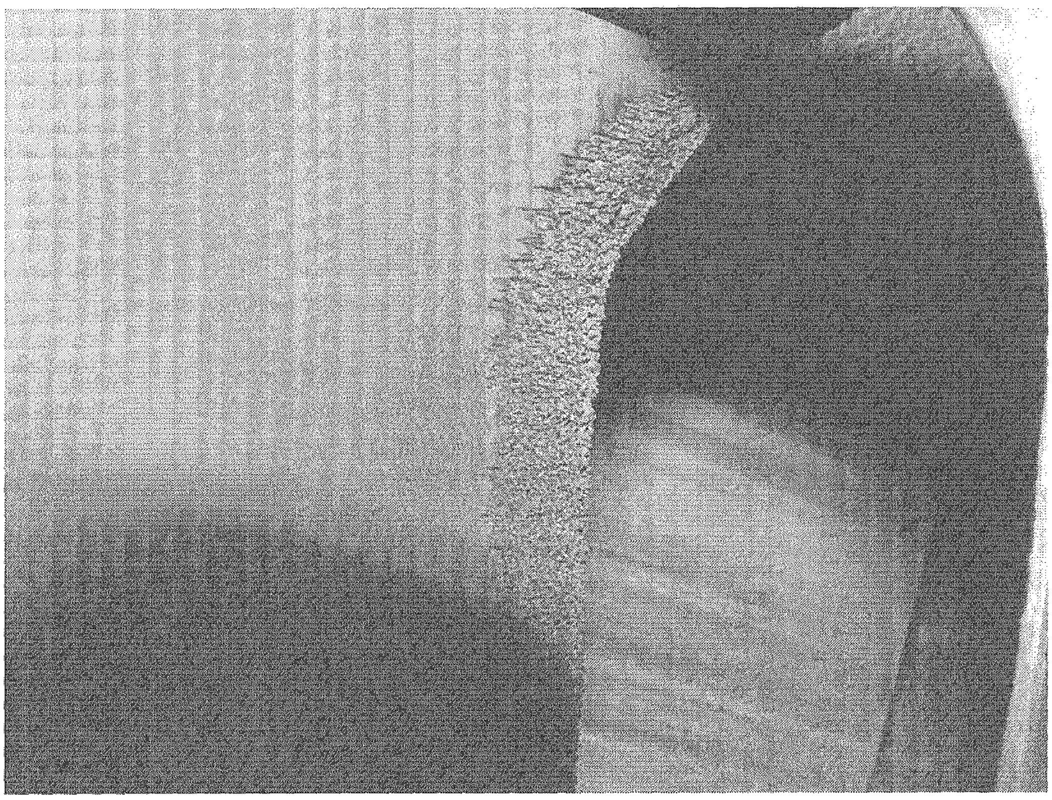
The proposal should provide the following options / information:

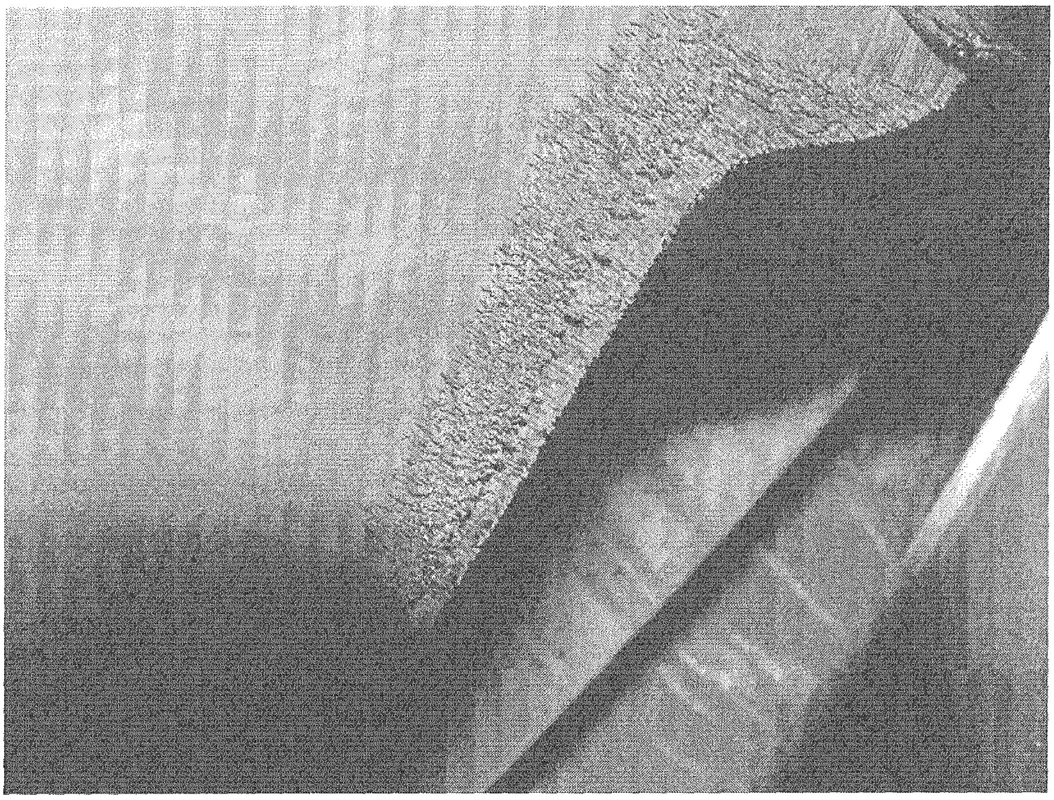
- Cost of blades on a per row basis, 6 rows each on Unit-1 & 2. Include options in cost per row basis: self shielded, braised-on Stellite shielded, and electron beam welded (EBW) Stellite shielded.
- Cost of hardware on a per row basis.
- Cost to install on a per row basis.
- Cost to perform a low speed balance performed on site.
- Proof of ISO-9001/2000 certification for blade manufacturing.
- Proof of possession of all raw materials for blades is in vendor's stock at time of award.
- Delivery options:
  - Total time to obtain forgings.
  - Time required to machine.
  - Time required for installation once rotor is removed from machine.
    - Vendor must prove the ability to install own blade design.
    - Vender must have the ability to install blades on site, with a proven record of doing such.

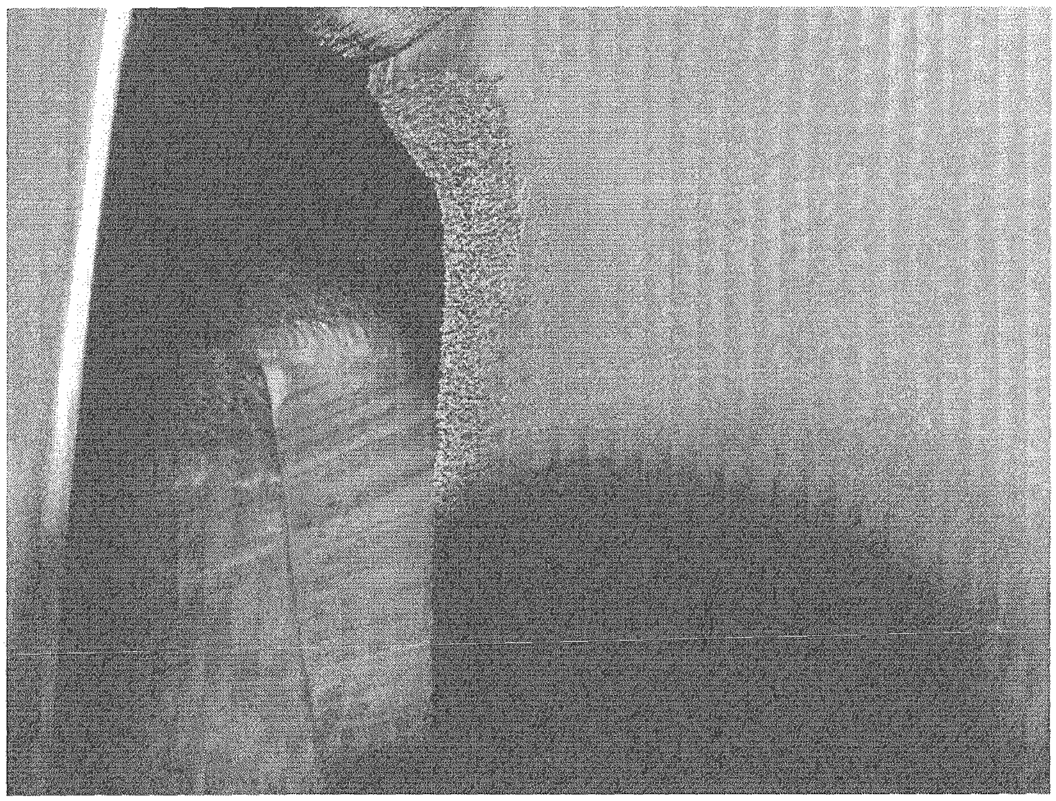
After review of proposals, a follow-up meeting may be held to discuss in detail any technical aspects of the design which needs to be clarified. IPP expects to review the finite element stress analysis (FEA) and reserves the right to obtain a third party in depth review of the FEA.

Technical questions should be directed to:

Dave Spence
Technical Specifications Director
435-864-6449







From Leo Molena – MPA

SPECIFICATION # XXXXXX

Rev 0
Month, Year

LOW PRESSURE STEAM TURBINE LAST STAGE RETROFIT FOR IMPROVED EFFICIENCY

Station Name UNIT # XX

Table of Contents

1.0 INTRODUCTION

This specification provides project specific requirements for low pressure steam turbine 30 " last stage buckets designed to provide improved reliability and efficiency on {Quantity} (X) units (Units X and Y) at the {Station Name} Power Station. Last Stage Blades on the A, B, and C low pressure steam turbines will be replaced.

The low pressure turbine last stage turbine projects shall incorporate the latest technologies to deliver the maximum reliability and efficiency at the present rated gross output and within the existing outer shell configuration.

The intent of this modification is to maximize efficiency without increasing plant MW output while incorporating component reliability with the latest advances in steam turbine technology.

The Contractor shall provide a complete scope of work to design, manufacture, install, {Customer Name} will use its in house labor force to perform turbine disassembly and reassembly activities.

It is not the intent of this specification to provide all details necessary to provide a complete scope of work.

This specification should be used in conjunction with Specification XXXX, "General Conditions", revised {Month, Date, Year}, and other {Customer Name} contractual agreements (Contract Documents) to provide requirements related to this project.

Packaged pricing is requested for the first unit to be modified {Station Name} Unit #X in April, 2010 as well as for Unit X in April, 2011.

2.0 FACILITY LOCATION

The {Station Name} Power Station (the plant) is a {Quantity) (X) unit, fossil-fired, power generating facility owned and operated by {Customer Name}. This facility is located on {Address}, {Station Name}, {State, Zip Code}. The phone number to the main office is {Phone Number}. The plant manager is Mr. {Plant Manager}.

3.0 TURBINE DISCRIPTIONS

The {Quantity} (X) units at {Station Name} have General Electric manufactured steam turbines of the S-2 design. These turbines are tandem-compound reheat units with three double-flow low-pressure sections.

The units are currently overhauled every {Quantity} (X) years. The overhaul interval will be extended to {Quantity} (X) years. The maintenance history for each unit is provided in Attachment A. More detailed maintenance records are available for review at the plant.

The most recent modified turbine test for each unit is provided in Attachment B. Additional turbine test information is available upon request.

The design data of each unit is provided below:

3.1 Unit X Design Data

Serial Number:	XXXXX
Speed:	3600 RPM
Last Stage Bucket (LSB) Length	30 inch
In Service Date:	Month, Year

3.2 Unit 4 Design Data

Serial Number:	XXXXX
Speed:	3600 RPM
Last Stage Bucket Length	30 inch
In Service Date:	Month, Year

Original plant heat balances are provided in Attachment C.

The A, B and C Low Pressure Turbine sections (turbine and generator ends) of Units X and Y currently have GE LP 30" last stage (L-0) buckets.

Units X and Y will be modified with continuously coupled blades which incorporate the latest advances in steam turbine technology.

4.0 SCOPE OF WORK

The work shall comply with all requirements of the specification(s) and incorporate the highest quality of design and workmanship. A complete scope of work shall be provided including all engineering, design, manufacturing, shipment, and installation, services, tooling,. The scope of work shall properly address all interfaces with existing plant components. It is not the intent of this specification to specify all details and services necessary to provide a complete scope of work.

{Customer Name} Maintenance Service Department (MSD) will supply the labor required for the turbine disassembly and reassembly.

The engineering, design and manufacturing scope shall include all shop and field inspections and measurements, development of new exhaust loss curves, compliance with applicable codes and standards, disposition of non-conformances, quality control, and documentation thereof. The installation scope shall include shop supervision, installation drawings and procedures, machining, tooling, hardware, and all modifications to existing components to properly accommodate the turbine bucket replacement.

The scope of work for each unit bucket replacement shall include, but is not limited to:

4.1 New last stage buckets for the A, B, and C low pressure turbines.

4.2 Updated turbine back pressure limit curve for the Last Stage Blade.

4.3 Thermal kit revision- exhaust loss curve for Last Stage Blade.

4.4 A warranty valid for a minimum of 1 year following the completion of the performance test.

4.5 If the Contractor is performing the installation in its shop, transportation of the rotors to the Contractor shop and the return of the rotors to the {Station Name} Power Station site.

5.0 CODES AND STANDARDS

Equipment covered in this specification shall comply with all currently approved applicable industry codes and standards, and all federal, state, and local safety and health requirements. The codes and standards shall include but not be limited to:

Short Term as Used Herein	Complete Identification of the Sponsor Organization
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
ASNT	American Society for Nondestructive Testing
ASTM	American Society of Testing Materials
AWS	American Welding Society
OSHA	Occupational Safety and Health Administration

If there is or seems to be a conflict between the specification(s) and a referenced document, the matter shall be referred to the {Customer Name} Engineer, who will clarify the matter(s).

Any non-US codes or standards that apply to components supplied under this specification shall be identified in the proposal.

6.0 DEFINITIONS

Engineer - The preparer of the Specification and the responsible party for all the requirements of and any changes necessary to the specification(s).

Company - This term shall refer to the equipment or material Purchaser, Customer and Owner which is {Customer Name} also referred to as {Customer Name}.

Contractor - Shall refer to a company submitting a proposal to fulfill the requirements of the specification(s) or the successful company who is awarded the contract and/or purchase order and who has accepted the overall responsibility for fulfilling the requirements of the specification(s). This term shall include any subcontractors that the Contractor may use.

Maintenance Service Department (MSD) – The {Customer Name} in house construction and maintenance organization that will be performing turbine retrofit activities.

7.0 TECHNICAL REQUIREMENTS

7.1 Design and Installation

The contractor shall incorporate the following requirements in the design of the new last stage buckets and new diaphragms (if required):

a. A high efficiency aerodynamic design
b. A material and vane design that provides superior protection against erosion.
c. A high structural integrity during normal operation and abnormal over speed conditions.
d. Protection against stress corrosion cracking and corrosion fatigue
e. Protective design features to guard against flow-excited vibration, flutter and fatigue.
f. Buckets covers are to have coupled construction and provide superior tip leakage control.
g. A maintenance interval of ten (10) years.

7.2 Manufacturing

The entire material procurement and manufacturing process shall be subject to a stringent quality control program. Upon Contract award, the Supplier will provide a Quality Inspection and Test Plan (QST) to the customer. This document will outline the QC operations, identify potential witness points, and denote the documentation that will be provided to the customer for record purposes. The customer will review and approve the QST with any agreed upon modifications. Two copies of all material certifications and test reports, as agreed to in the QST document, shall be supplied to the customer as soon as they are available, and or applicable.

Access to the Contractor's manufacturing facilities, offices, and personnel shall be provided to {Customer Name} representatives, or their agents, for the review of work in progress, testing, quality control, or manufacturing. For agreed upon witness points, the Contractor shall notify at least 15 working days prior to any testing, so that {Customer Name} may witness the testing.

Nondestructive testing procedures shall be submitted to {Customer Name} for review and approval. The contractor will provide its NDE procedures and associated qualifications and certifications for NDE personnel for review and approval by a {Customer Name} (Level 3 inspector). Baseline NDE inspection reports will be provided to {Customer Name} as soon as possible and within thirty (30) of the inspection date.

7.2.1 Balancing and Overspeed Tests

The rotors are to be low speed balanced tested. Certified documentation of such test results shall be forwarded to the {Customer Name} engineer upon completion. Contractor shall provide a sufficient assortment of balance weights should field balancing be required during startup.

7.3 TESTING

Visual Inspection

Visual inspections shall be conducted throughout the manufacturing and Installation processes to maintain proper quality control standards.

Radiographic Inspection

All documentation data including final acceptance films for all radiographs shall be made available for review and acceptance by the Company prior to release for shipment of the inspected components.

Manufacturing Standards, Inspections & Tests

Components shall be manufactured from materials made using state of the art melting, refining, heat treatment and manufacturing processes. The nondestructive testing, mechanical testing, quality control procedures, and quality assurance programs applicable to these components shall assure that they are of high quality and suitable for long term reliable service. Certified material test reports and certified reports of the results of additional tests such as impact tests shall be provided for the components, as applicable.

The Contractor shall identify the following information for each component with their proposal:

- The standard specification and material grade/class applicable
- The heat treatment, mechanical, and nondestructive requirements , as applicable, for standard materials supplied
- For components manufactured from proprietary materials identify the material composition, heat treatments, mechanical properties and testing, nondestructive testing, stability testing, and identification marking requirements specified by the manufacturer
- Weld repair limitations and process and inspection requirements if weld repair is permitted
- Material suppliers and country of origin
- Certified material test reports to be provided

8.0 SCHEDULE

8.1 Milestone Dates

The first turbine bucket replacement is tentatively scheduled for installation in Unit X beginning April, 2010. . Unit Y will be installed in April, 2011. Exact schedule dates will be determined later.

Delivery Dates

Delivery of all turbine components is required to meet the outage schedule.

Award of Contract

All proposals must be submitted within {Quantity} weeks of the RFP issue date. The date for the award of the contract for the turbines is expected within {Quantity} weeks from the receipt of proposals.

Payment Schedule

The Contractor's bid should propose a payment schedule showing release dates for engineering, material procurement, etc. The contract award date should coincide with the engineering release payment. In addition to the payment schedule, a cancellation charge schedule shall be provided that would show the costs if the project is canceled.

Design/Manufacturing Schedule

Within one (1) month of award of the purchase order, the Supplier shall provide a detailed design and manufacturing schedule. The schedule will contain sufficient detail to track monthly progress and provide dates for various testing and inspection. The schedule will include engineering activities and potential witness points. It will also show the remaining float for each activity. Monthly updates will be required.

Approval Drawings

Customer shall have the opportunity to view all drawings during mutually agreed upon meetings.

9.0 INSTALLATION

The Contractor shall provide supervision, engineering, tooling, specialized machining and services necessary to perform the following scope of work: on site

1.0 Shipment of the A, B, and C rotors from {Station Name} loading bay to the Contractor shop and the return trip (if required). no shipping
2.0 Dimensional checks of the rotor
3.0 Removal of the existing last stage buckets pins and buckets including any necessary drilling of pins
4.0 Preparation, cleaning, and NDE of bucket wheel dovetails
5.0 Inventory of new turbine components
6.0 Installation of new last stage buckets, pins, and covers
7.0 Specialized clearance machining
8.0 Low speed balancing

The Company will use its in-house MSD labor for onsite turbine disassembly and reassembly.

9.2 Company Responsibilities

{Customer Name} will supply the required labor for the turbine disassembly and reassembly.

10.0 DOCUMENTATION

10.1 Fabrication Schedule

The Contractor shall prepare and submit a fabrication schedule showing estimated dates for turbine bucket rows:

1. Start of procurement activity
2. Start of fabrication
3. Manufacturer's inspection points
4. Major production milestones
5. Completion of fabrication

10.2 Documentation Required for Delivery

10.2.1 Approved QC Documentation List

A copy of the appropriate Company QC Documentation List shall be included with each documentation package delivered. During preparation for final documentation and shipment, the Vendor will compile the documentation package and indicate the quantity of each type record.

All required documentation should be furnished upon, or prior to, the arrival of the hardware at the site. If requested, the Certificate of Compliance accompanying the shipment will be accepted with the required documentation package to follow within ten days. Final acceptance of the equipment will not occur before the complete documentation package is received.

11.0 SHIPMENT AND DELIVERY

Materials manufactured for this specification are to be stored indoors until ready for shipment. If there is a possibility for temporary outdoor storage of any components they shall be packaged to protect them from corrosion damage.

All turbine components shall be properly supported and weatherized to prevent damage from occurring during loading and shipment. All damage incurred during loading and shipment shall be repaired by the Contractor at his expense. The Contractor shall be responsible for shipment of all turbine bucket components. It will be the Supplier's responsibility to deliver all components into the shop bay, under the crane hook, where they can be immediately lifted with no extra work required.

All turbine components shall be delivered to the site at least {Quantity} (X) weeks prior to the outage start date for inspection.

The lifting weight and center of gravity shall be prominently marked on all delivered components.

12.0 SPARE PARTS

13.0 WARRANTY

The Contractor shall warrant that the equipment described in this specification and all its parts shall be free from defects in material, design, and workmanship. This warranty shall extend for a minimum of twelve (12) months after commercial operation and shall be extended for another year if failure of equipment parts requires replacement or repair. Replacements or repairs within this period shall be at Contractor's expense.

14.0 CORRESPONDENCE

All correspondence including schedules, drawing transmittals, inspections, procedures, plans, submittal letters, etc. shall be submitted to the {Customer Name} {Group Name}., , Attention: Mr. {Name},{Address}..

Contractual correspondence relative to prices, terms, conditions, price adjustments and other commercial matters shall be addressed and submitted to the {Customer Name} {Group Name}., , Attention: Mr. {Name},{Address}. All correspondence shall reference the Company Purchase Order Number and the Contractors Job Order Number.

15.0 ATTACHMENTS

A- Turbine Maintenance Histories
B- Modified Turbine Tests
C- Plant Heat Balances

Productivity Improvement for Fossil Steam Power Plants, 2006

1014598

Final Report, December 2006

Authors
A. F. Armor
S. H. Hesler

EPRI Project Managers
A. F. Armor
S. H. Hesler

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

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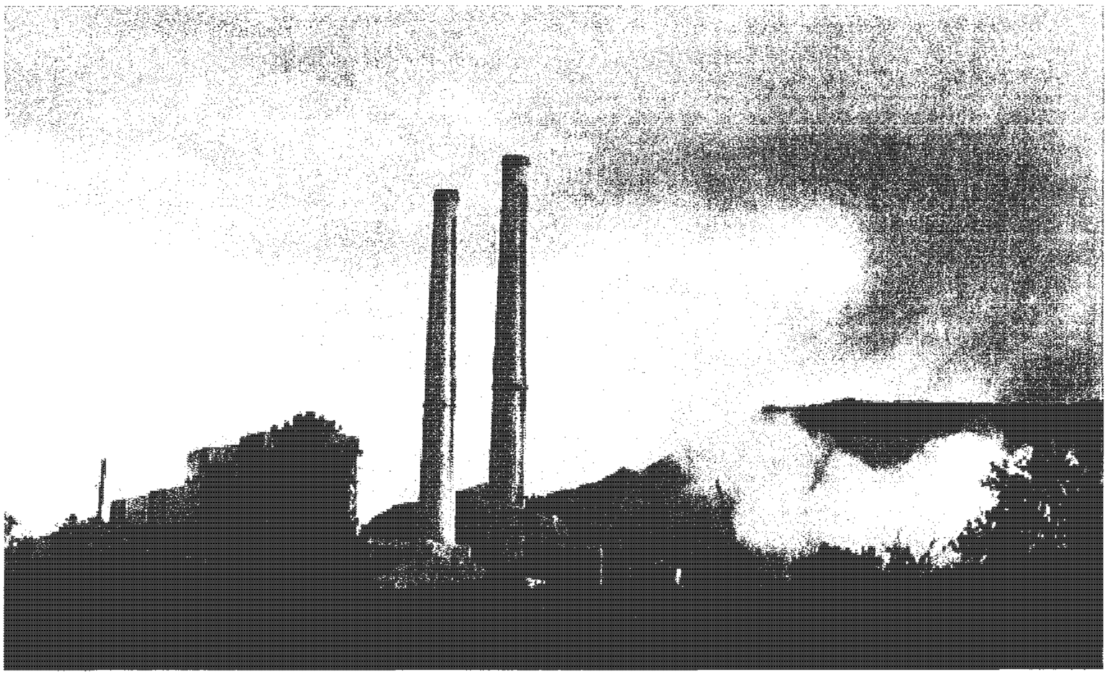
PacifiCorp Detect Cracks at Huntington 1 Unit in Self-Shielded Last Stage Turbine Blades Leading to Recommendations on Repairs and Inspection Procedures



The PacifiCorp plant at Huntington, Utah, had a failure in 2004 at its 477 MW unit 1. This was an in-service failure of a 33.5" self-shielded last stage turbine bucket. The failure occurred when the unit was at steady-state full load conditions. The crack initiated at an erosion crevice on the leading edge of the blade and traveled across the blade foil.

Issues/Goal (Text From [1])

During August 2004, the PacifiCorp Huntington Station Unit 1 GE D8 turbine experienced an operational failure of a self-shielded 33.5" last stage bucket, resulting in a 30-day unplanned outage and a $4 million bucket replacement and repair effort. The failure appears to have resulted from a high-cycle fatigue crack that developed at a leading edge erosion crevice and propagated to failure before detection. There had been four similar failures of self-shielded buckets in units owned by Southern Company and AmerenEnergy (AEG).

In the mid 1970s and early 1980s, GE began manufacturing the 26", 30" and 33.5" stellite-shielded last stage buckets from Jethete M152 material with a measured hardness of about 370 HB (vs. 327 HB spec.), and eliminated the electron beam weld-attached (EBW) stellite erosion shield. This version of bucket design was termed by GE to be 'self-shielded' because raising the material hardness was supposed to resist erosion along the leading edge of the bucket in the same manner as the stellite shield. The self-shielded buckets resist erosion, but present a different wear pattern than the stellite shielded buckets. When a self-shielded bucket is eroded, the nose of the blade contains numerous sharp crevices that have very small micro cracks at the bottom of the crevices. Once the micro cracks start to grow, the crack propagation rate appears to be greater in the harder material than in the more ductile, shielded buckets. This increases the probability of a crack reaching critical flaw size before detection.

It was noted that PacifiCorp, Southern Company and AEG have not had a single in-service failure of the earlier version 30" or 33.5" stellite-shielded last stage buckets, although many rows of those buckets have been in service for 30-35 years. It appears therefore that the self-shielded buckets have a shorter service life and are more prone to in-service failures than the EBW stellite-shielded buckets.

For the aging (1960-1985) GE fleet of over 200 turbines with over six hundred rows of 30.0" and 33.5" last stage buckets, it is expected that last stage bucket replacement could be an issue in the coming years. The preferred choice for replacement buckets may be the stellite-shielded version, but currently no one is manufacturing them. It may be prudent to delay replacement of existing buckets until shielded replacement buckets are again manufactured as an option.

This case study analysis seeks to assess the failure causes, and recommends ways for future protection from erosion of last stage buckets.

Key Conclusions

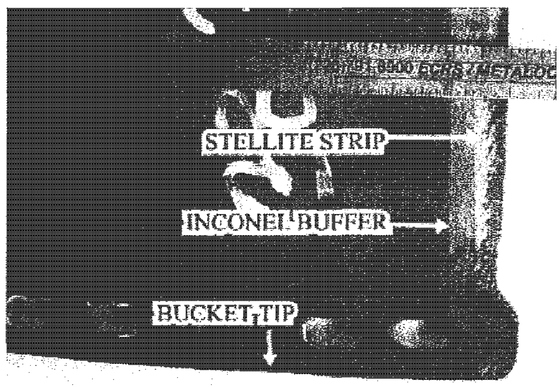
The self-shielded bucket elevated material hardness appears to shorten the service life and pose an increased risk of in-service bucket failures. There is also a possibility that both shielded and self-shielded buckets may develop cracks in areas outside the erosion zone near the blade tip. Cracks between the base and mid-blade may pose the risk of a catastrophic failure.

One course of action [2] is to gather a fleet history, develop standards for inspection techniques and intervals, and to provide options for bucket replacement. More specifically:

1. For fleet owners and operators of GE turbines with 26", 30" and 33.5" last stage buckets, inventory units to determine bucket design, material, age and inspection and repair history.
2. Establish a user's group to collect information about the fleet operating history of the GE 26", 30" and 33.5" last stage buckets. The operating history would be used to determine the service life expectancy of buckets based on size, design, material type and unit operating history.
3. Encourage development of in-situ inspection techniques that test the entire bucket, from base to tip for cracks and accumulated fatigue damage.
4. Establish recommended inspection intervals based on bucket design, material, age and service duty.
5. Encourage contingency planning to prepare plant personnel for the course of action to be taken when in-situ inspections disclose cracks in buckets.
6. Propose that manufacturers develop the capability to manufacture stellite-shielded buckets as a replacement option.
7. Conduct a cost/benefit analysis comparing the shielded and self-shielded last stage buckets.

Solutions and Problems

There have been a number of design evolutions and material changes in the 33.5" last stage buckets since they were first introduced in 1960:

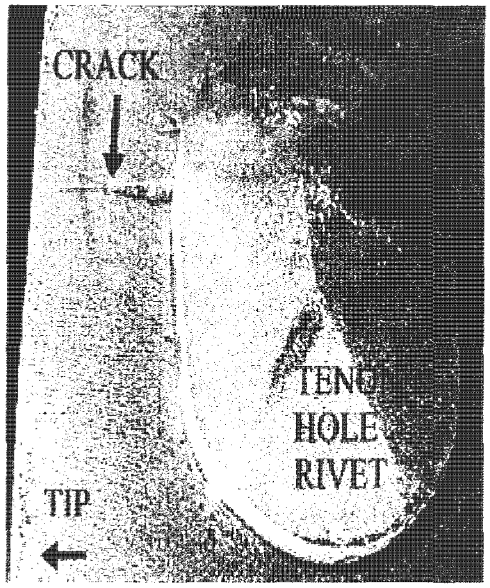


33.5" shielded bucket. The stellite erosion shield and Inconel buffer extend approximately ½" from the nose across the face of the blade.

1. **MK I** – The original design was a 422 Stainless Steel bucket with a hand-welded on formed stellite shield. Welding was done using the TIG process with Inconel as the filler metal.
2. **MK II** – This design was similar to the MK I, but the stellite erosion shield, which was a solid formed bar along the outer blade nose, was attached by electron beam welding with Inconel filler. **MK III** – Same as MK II except larger nub for tie wire – 422 Stainless Steel bucket.
3. **MK IV** – (est. 1973) Changed bucket material to Jethete M152 and continued attachment of stellite erosion shield. Slightly higher tensile strength; hardness approximately the same as the 422 SS, 327 HB. Over-twist design, larger nub, cover with larger tenon holes.
4. **MK IV** – (est. mid to late 1970s) Discontinued attachment of the stellite shield. Bucket was termed *'self-shielding'* because the hardness of material was increased to 360 - 370 HB to resist erosion without using a stellite shield. Elimination of welded stellite shield may have reduced the bucket manufacturing costs potentially by as much as 20%.
5. **MK IV** Heavy – (est. introduced in 1990) – same material as MK IV and has heavier tenon boss and blade length extended to 34.5", self-shielded. If retrofit, this modification requires machining the last stage diaphragm to accommodate the larger bucket diameter, and replacement of the flow guides.

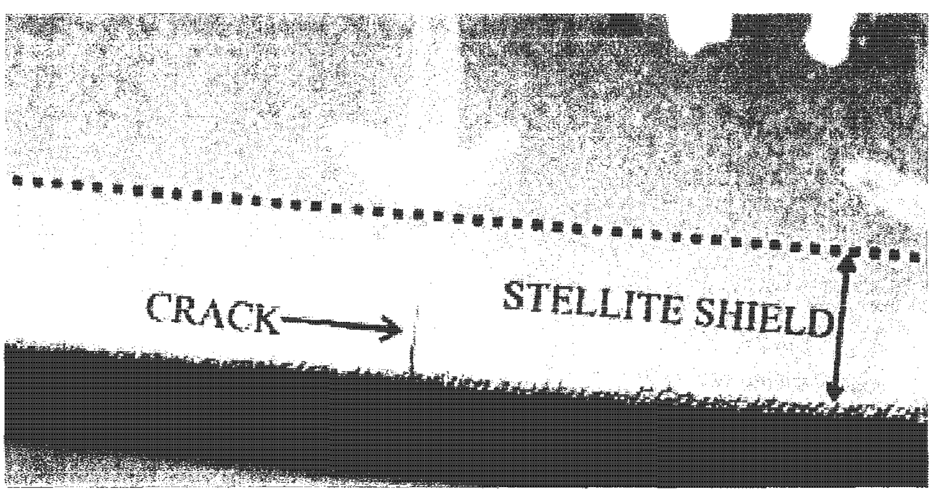
The 33.5" buckets in general have had a good fleet reputation except for cracks that occur at the tip of the buckets. Each bucket has a riveted spacer block that acts to continuous-couple the buckets at speed. It is not uncommon for cracks to start in the tenon hole and propagate to the tip of the blade. However PacifiCorp is unaware of any instances where tenon-hole cracks have resulted in a significant in-service blade failure. Note the Dave Johnston Unit 4 LP LSB tenon-hole crack indication, from April 2005.

It has been GE's recommended practice that buckets with the tenon cracks be replaced rather than weld-repaired. It was demonstrated in 2003 at the Dave Johnston Station that these tenon-hole cracks could be successfully weld repaired and post-weld heat-treated without removing the buckets from the rotor. Over the past 25 years, self-shielded Jethete M152 buckets have replaced the ones with cracks at tenon holes. This resulted in a mixture of bucket types in rows that previously had only stellite-shielded buckets.



Operational Factors Causing Cyclic Fatigue

Elevated backpressure, low-load operation, saturated steam washes and unit start-ups and shutdowns can cause steam flow disturbances that allow blade vibration and induce cyclic fatigue damage of the blade material. The resistance to the fatigue damage that a bucket sustains will vary depending on material and hardness. Accumulated fatigue damage until recently could not be measured by non-destructive test methods so problems were typically not detected until cracks develop at stress risers such as tenon holes, pits from corrosion, and erosion crevices, etc. In the Jethete M152 self-shielded buckets, there is no Inconel attachment-weld buffer zone to stop a leading-edge fatigue crack. The increased hardness of the self-shielded blade material seems to contribute to accelerated crack growth, reducing the opportunity of pre-failure detection. This presents challenges when attempting to plan bucket replacement cycles for near-end of the service life, and to assess the risk associated with postponing bucket replacement until cyclic fatigue cracks develop.



In the stellite-shielded buckets (both 422 SS and Jethete) fatigue cracks that develop in the stellite shield zone of the blade generally do not propagate beyond the Inconel barrier of the attachment weld and can be removed by buffing or light grinding. See above the figure of a leading edge crack in the satellite shield of a Dave Johnston Unit 4 bucket.

In the Jethete M152 self-shielded buckets, there is no Inconel attachment-weld buffer zone to stop a leading-edge fatigue crack. The increased hardness of the self-shielded blade material seems to contribute to accelerated crack growth, reducing the opportunity of pre-failure detection. This presents challenges when attempting to plan bucket replacement cycles for near-end of the service life, and to assess the risk associated with postponing bucket replacement until cyclic fatigue cracks develop.

Risk Assessment

Operating history, crack location, bucket design and bucket material type are keys to evaluating the probability and consequences associated with operating a unit until the cycle fatigue damage is manifested. Cracks located in three different areas of the bucket may pose different levels of risk depending on bucket style and material:

1. **Spacer-block Tenon Cracks:** Although there is a rather high incidence of tenon cracking, PacifiCorp is unaware of any incidents of a tenon crack that has liberated a spacer block and caused significant turbine or condenser damage. The risk of an in-service failure from this type of crack is considered low. This type of cracking has been found in all generations of the 33.5" PacifiCorp last stage buckets.
2. **Leading-edge bucket cracks along erosion zone near bucket tip:** This area of the bucket suffers moisture-related erosion. The erosion crevices provide numerous crack-initiation sites for high-cycle fatigue damage.
   - **Stellite-shielded buckets:** Both the 422 Stainless and Jethete shielded buckets are resistant to crack propagation because cracks typically stop at the Inconel zone of the attachment weld, which allows an opportunity to detect and remove the crack during normal overhaul cycles. The risk of an in-service failure from this type of crack is viewed as 'low' in shielded blades.
   - **Self-shielded buckets:** Cracks that develop in this zone of the self-shielded buckets are more frequent because the erosion crevices are deeper and sharper than in the shielded buckets, and the cracks seem more likely to propagate quickly and grow to critical crack size than in the more ductile shielded buckets. The risk of an in-service failure from this type of crack appears to be significantly greater than in a shielded bucket.
3. **Cracks in bucket areas outside of the tenon holes and tip leading edge:** At the Dave Johnston and Huntington Stations, cyclic fatigue cracks of this nature were found and addressed before failure in five buckets since 1997. Two cracks were in stainless shielded buckets, and three were in Jethete self-shielded buckets, so it is assumed that each style and material of 33.5" bucket is susceptible to these high-cycle fatigue cracks occurring outside the stellite shield zone. The frequency of crack occurrence is less than scenarios 1 and 2, but the consequences of an in-service failure are potentially catastrophic if a blade separates between the base and mid-bucket. Cracks in self-shielded Jethete blades with hardness greater than 350 HB are of concern because they seem more likely to reach critical crack size before detection than in the more ductile shielded buckets with a hardness less than 350 HB.

PacifiCorp Unit History for 33.5" LSB's

PacifiCorp owns and operates four GE Model D8 turbines and has ownership in three other D8 turbines not operated by PacifiCorp. The units, which were all commissioned between 1972 and 1983, have been in base load operation. The turbines are tandem-compound reheat units, with double-flow low-pressure sections. The last stage buckets are 33.5" in length and weigh approximately 38 lbs. each, exerting a centrifugal force in excess of 470,000 pounds of force at synchronous speed. The cover piece (or tenon block) exerts over 2000 pounds of force at speed.

In Summary

Dave Johnston Unit 4 - 330 GMW, 1971 - Glenrock, Wyoming (MK II buckets, shielded, 422 Stainless Steel).

- Pre 2003: One cracked sleeve was replaced, 22 spacer blocks were replaced because of rivet cracks, and one tenon-hole crack was weld repaired.
- 2003: (32 years service life last stage buckets) Dismantled inspection - Cracks from high-cycle fatigue were found in the leading edge of two buckets, approximately 4-6" from the base of the bucket. Those two buckets were replaced with new buckets. Additional crack indications were found along the stellite shields of eight buckets; these cracks were ground out and polished. The cracks in the stellite did not progress beyond the Inconel buffer zone of the attachment weld. Other buckets were cracked at the tenon holes and were weld repaired. The unit had been inadvertently operated at or slightly above the 5.0" Hg condenser backpressure limit for two months in the year before the dismantled inspection and it is thought that the elevated backpressure was a contributor to the development of high-cycle fatigue damage in the blades.
- 2005: (34 years service life last-stage buckets) Last stage buckets were replaced with self-shielded Jethete buckets.

Hunter Unit 3 – 475 GMW, 1983 – Castle Dale, Utah (shielded Jethete M152 buckets)

Pre 1998: No previous last stage bucket repairs. Turbine HP/IP section had the advanced-design steam path modification and boiler capacity was increased, which caused an equivalent steam-flow increase of 10% at the turbine inlet. A GE evaluation of the last stage buckets showed loading to be 5% above normal because of the increased steam flow and the reheat attemperation-spray flow. Based on their design review and the fleet operating history of the 33.5" buckets, operation at the proposed limits was approved.

2004: Post Huntington Unit 1 failure - an in-situ dye penetrant test of the bucket leading edges was completed and no crack indications were found.

2005: Since the 1998 turbine modification, the unit has been unable to sustain the condenser backpressure levels that were typical before the modification (less than 3.0"Hg). Backpressure at full load is typically 4.0"– 5.5"Hg. The issue of what effect operating at elevated backpressure would have on L-0 bucket loading and stability is still being reviewed. In April, the last stage buckets were inspected by Reinhart and Associates using an eddy current test probe – no cracks were detected.

Huntington Unit 1 – 470MW, 1977 – Huntington, Utah

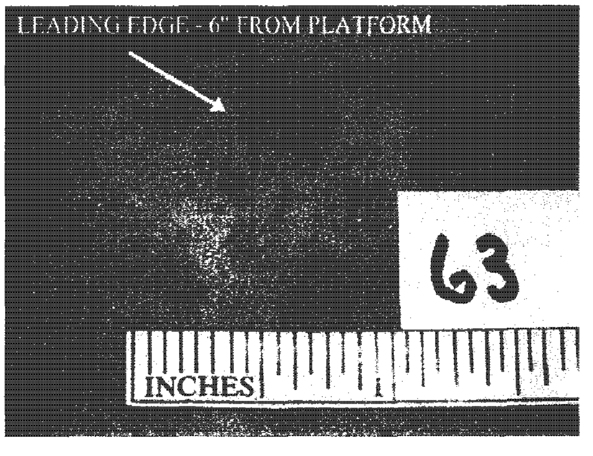
Pre 1997: From available historic records, it appears the only last stage bucket activity was replacement of dovetail pins.

1997: During the planned dismantled inspection, cracks were found in three Jethete self-shielded last stage buckets. The crack locations were as follows:

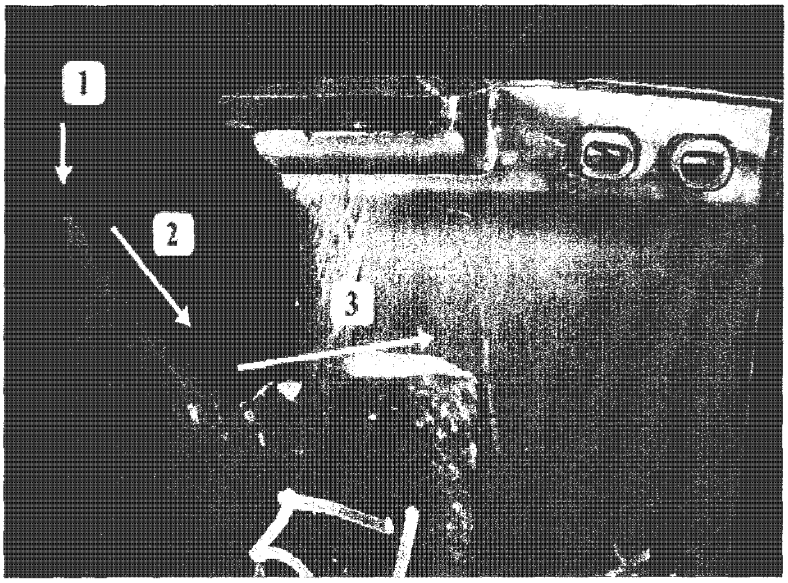
1. Leading edge, 6" from base platform
2. Trailing edge, 20" from base platform
3. Trailing edge, <1" from tip of blade

The cracked buckets were replaced and then sent to Radian (now M&M Engineering) for metallurgical analysis. The analysis showed the crack failure mechanism to be high cycle fatigue and the cracks did not occur at the highest stress area of the blades.

2004: In August, HTG1 suffered an in-service failure of a 33.5" self-shielded last stage bucket. The failure occurred when the unit was at steady-state full load conditions. The crack initiated at an erosion crevice on the leading edge of the blade and traveled across the blade foil. M&P Laboratories, Schenectady, NY, determined high-cycle fatigue was the failure mechanism. When the bucket tip and spacer block separated, collateral damage occurred to the other buckets in that stage and the mating diaphragm. The mating diaphragm and other buckets in the failure row sustained damage from the liberated tip and spacer block, but collateral damage was minimal. Turbine shaft vibration did not exceed a level that would initiate damage of seals. Because of leading edge erosion, and cracks that were found at the tenon holes of 30 other buckets, the decision was made to replace both rows of the Huntington L-0 buckets with new MK IV self-shielded buckets. Huntington Unit 1 had a combination of shielded and self-shielded buckets.



The crack in Bucket 63 was readily visible, having cracked through-wall for a length of over 1" at the leading edge of the bucket, approximately 6" from the base of the bucket. The consensus of experts involved at that time was that an in-service failure was imminent and that the blade mass involved may have resulted in gross imbalance and extensive turbine damage.



Repair Costs

The bucket replacement was accomplished in a 30-day period at a cost of approximately $4 million. There were additional losses from lost generation sales opportunities, and due to the purchase of replacement power for the 470MW unit.

Huntington Unit 2 – 470 GMW, 1977 – Huntington, UT

This unit has a mix of shielded and self-shielded Jethete M152 buckets.

Pre 1992: No record of last stage bucket repairs.

1992: Scheduled dismantle inspection. Spacer-block tenon-hole cracks were found in 23 last stage buckets. GE replaced all 23 buckets with Jethete M152 self-shielded buckets.

1998: Eleven last stage buckets with tenon-hole cracks were replaced with buckets removed and repaired during the 1992 dismantle. Those buckets had been repaired by removing approximately 3" of the tip of the bucket and replacing with a new tip and a new stellite strip was submerged-arc welded on the buckets.

Units With Full or Partial Ownership, But Not Operated by PacifiCorp

Arizona Public Service Cholla Unit 4 (375 GMW, 1981)

This unit has no reported history of 33.5" last stage bucket problems. Buckets are shielded Jethete. The unit has been operated at elevated backpressure, 4.5-5.0"Hg. Measures are being taken to inspect the buckets in-situ at the first opportunity. Since the unit has a history of high backpressure operation, the last-stage bucket service life may be shortened and buckets should be periodically monitored for cracks.

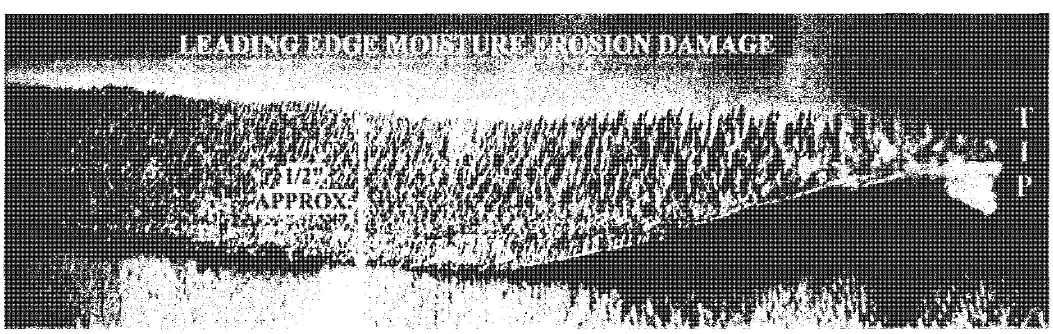
Tri-State Generation Craig Units 1 & 2 (411 MW, 1980 & 1979)

These units have 33.5" last stage buckets, shielded, but material type has not been determined. The history shows welded repair of several buckets that had cracks originating at the tenon-holes. The Unit 1 last dismantled inspection was in 2003 and Unit 2 in 2004; that was the last time buckets were inspected. Periodic in-situ inspections are being considered, and would be done during extended forced outages or planned outages.

Other Companies' Experiences

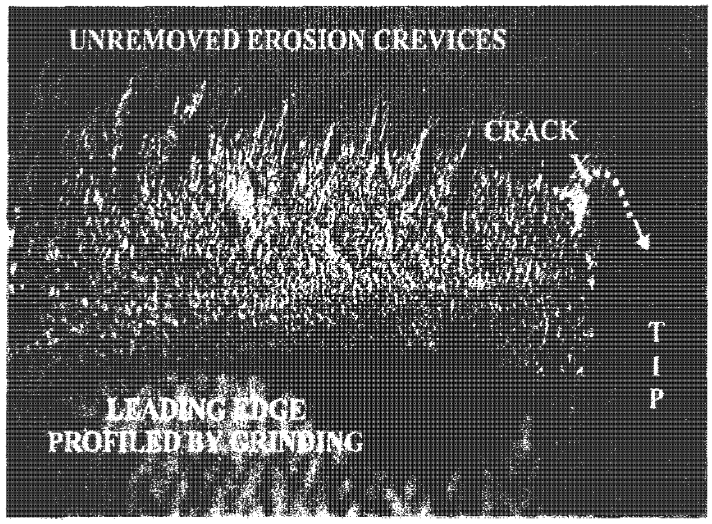
AmerenEnergy (AEG) Coffeen Unit 2 (590 MW)

Ameren owns and operates the Coffeen Power Station in Coffeen, Illinois. The 590 MW Coffeen Unit 2 is a swing-load unit that operates in a range of 40-100% rated load. It has a cyclone sub-critical once-through boiler that makes it difficult to maintain reheat temperature at lower loads. Backpressure is typically below 3" Hg, but there are brief excursions in the summer to 3.5" Hg. The GE Model G2 steam turbine has two double flow low-pressure turbines with 30" last stage buckets. The unit was placed in commercial service in 1972 and operated for 22 years before the last stage buckets were replaced in 1993 because of tie wire cracking. Heavy erosion of the satellite-shielded buckets was also observed. The replacement buckets were the GE Jethete M152 'self-shielded' buckets, and experienced heavy moisture erosion along the leading edge. The erosion wastage created crevices along the leading edge, with the deepest crevices near the tip of the buckets.



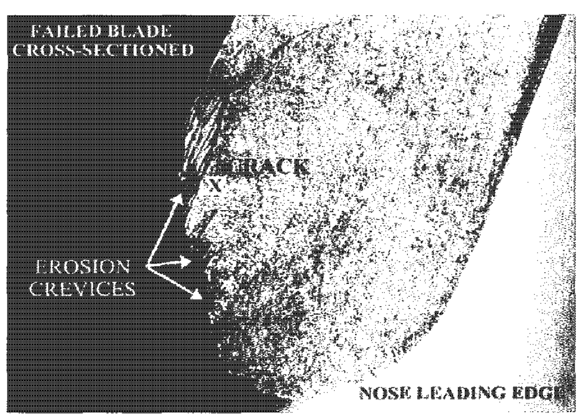
In March of 2004, when the replacement buckets were approximately nine years old, the first in-service failure of these buckets occurred. While the unit was in operation, the tip of a bucket liberated and necessitated a two-week outage for repairs and replacement of several buckets. An analysis of the failed bucket disclosed that a crack had initiated in a moisture-erosion crevice approximately ½" from the original nose of the bucket, near the tip where the deepest erosion crevices existed. The crevice notch served as an initiation site for a high-cycle fatigue crack.

After the failure, the last stage buckets were inspected, the damaged buckets were replaced, and attempts were made to eliminate the worst of the foreign object damage along the bucket leading edges near the tip of the buckets by grinding and contouring the erosion areas. The unit was returned to service with the intent of operating it until a scheduled dismantled inspection in February 2005.



But, during the first week of January 2005, another last stage bucket failed while the unit was in service. The crack location and failure mechanism was nearly identical to the failure that had occurred previously. The failure was in a blade that had been contoured in March.

So, in less than ten months since all last stage buckets had been inspected and determined to be suitable for service, a crack had developed and progressed to failure. The failure necessitated a six-week early start of the scheduled 2005 overhaul. During the overhaul, both rotors were replaced with new GE rotors that have the 33.5" self-shielded Jethete M152 last stage buckets.



Units Featured With Start-Up Dates

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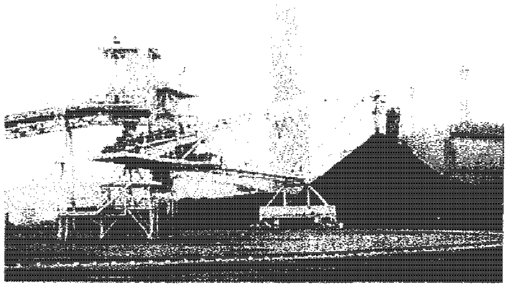
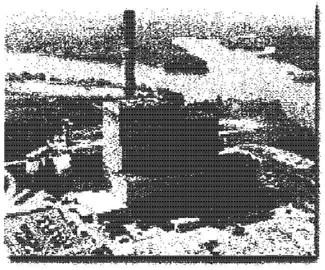
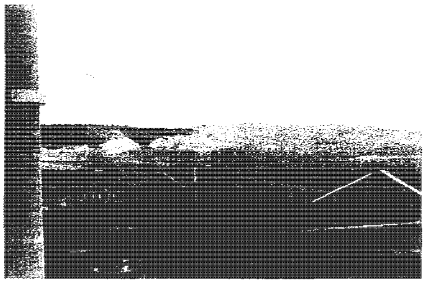


PacifiCorp Huntington, 2X 477 MW units, 1977, Huntington, UT



PacificCorp, Dave Johnston, Unit 4, 330 MW, 1971, Glenrock, WY



Ameren, Coffeen Unit 2, 590 MW, 1972, Coffeen, IL

TriState, Craig, Craig, CO Units 1, 2, 2x411 MW, 1979/1980

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2. AEIC conference, Barry Cunningham, Sr. VP of Electric Operations, May 5, 2005, Dallas, TX.

Contacts

Tom Kurtz, TK Inspection Service, (Boiler/Machinery loss prevention consultant for PacifiCorp), thomaskurtz@msn.com. (303) 770-2567

Paul Sabec, PacifiCorp Dave Johnston Station, Lead Senior Engineer, paul.sabec@pacificorp.com, (307) 436-2040

Dennis Sullivan, AmerenEnergy, Plant Staff Support Engineer, dennis.sullivan@ameren.com (217) 342-7993

Jim Carlson, Southern Company, Turbine Support Engineer, jhcarlso@southernco.com, (205) 992-6584

Gary Crisp, Tri-States Generation Craig Station, Turbine Engineer garci@tristategt.org, (970) 824-4411 ext.4510

Chris Pringle, Arizona Public Service Cholla Station, Turbine Engineer springle@apsc.com, (928) 288-1424

Mark Breslin, Maranda Technical, (Turbine consultant for PacifiCorp) marandatec@aol.com, (518) 339-2345

Critical Assessment – Steve Hesler, EPRI, 704-595-2183, shesler@epri.com

This case study at PacifiCorp's Huntington Unit 1, and at other units that utilize GE 33.5 inch last stage buckets, illustrates an issue of growing importance when operating steam turbines today.

Moisture erosion is a continuing problem in the final stages of LP turbines, especially as the wetness levels increase with improved efficiency and the tip diameters increase. Local hardening of the blade tip leading edge and the use of shields have been reasonably successful in the past. In the case of stellite shields, replacement of eroded shields can cost-effectively extend the life of the blades.

In the case described above, the self-shielded blades were heat-treated to a high hardness level throughout the entire component, not just the leading edge. The result is a blade that is not sufficiently tolerant to erosion notching. It was also noted in a subsequent stress analysis that there was a high probability of vibratory stress at the same vane location as the erosion notches – further limiting the expected life of this blade. The solution is to install a modified blade design that has a stellite shield, and to ensure that the vibration modes are well-tuned to avoid resonance with harmonics of shaft speed.

For those plants managing risk of fatigue cracking in blade vanes, like that described above, there is a promising new NDE technology designed to detect pre-crack fatigue damage in thin cross-sections such as airfoils. The ultrasonic method will be benchmarked by EPRI in the research project described in EPRI Supplemental Project Notice 1013029 dated July 2006. If successful, plant owners will for the first time be able to determine when a blade is likely to develop fatigue cracks, rather than wait for the cracks and assume the risk of a short time to propagate crack length to critical size.

Relative to erosion damage, another EPRI Supplemental Project was introduced in January 2006 and is described in EPRI document 1013086. The goal of the project is to determine qualitatively whether a hydrophobic coating applied to the stationary blades upstream of the L-0 rotor blade will alter the moisture transport characteristics and result in less water droplet damage. The liquid film on the stationary blades is the primary cause of the water damage, and if the hydrophobic coating reduces the amount of water in the film, the level of damage would be expected to be reduced as well.